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PHYSIOLOGY FOR BEGINNERS

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FOR

BEGINNERS

BY

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PREFACE

THIS little work is intended for those who, without any previous knowledge of the subject, desire to begin the serious study of Physiology. It is written in a more elementary and didactic manner than the *Elementary Lessons* of Professor Huxley, and, it is hoped, may serve as an introduction to that volume. Though the whole has been supervised by Professor Foster, who therefore holds himself equally with Dr. Shore responsible for its contents, the work belongs to the latter, since he has written it.

A sound knowledge of Physiology cannot be gained without some acquaintance with Chemistry and Physics, and at least a rudimentary knowledge of these ought to be obtained before the study of physiology is even attempted. Knowing, however, how frequently a book on physiology is taken up without any such previous acquaintance, we have given a few chemical and physical facts as preliminaries in chapter i. This chapter may therefore be considered rather as one to be used for reference than as one to be mastered from the first. The same to some extent applies also to chapter ii. The importance of carrying out the directions for actual observation given throughout the book cannot be too much insisted upon. The material required and the appliances necessary may be so easily obtained (even the cost of a useful microscope need not exceed £3) that there can be no excuse for neglecting such practical studies. It is very difficult, if not impossible, for the young to understand, for instance, the structure and working of the heart unless they actually see one; and so with many other parts of the subject. Even the things which can be learnt without actual observation are learnt far more quickly and surely with it. Every teacher who teaches the subject practically, knows how well he is repaid for the trouble which the practical teaching has given him.

A very large number of the figures have, by kind permission, been taken from Professor Huxley's *Elementary Lessons*, and one or two from Professor Mivart's *Elementary Anatomy*; the rest are either entirely new, or modifications of well-known figures.

M. FOSTER.
L. E. SHORE.

CAMBRIDGE, *August* 1894.

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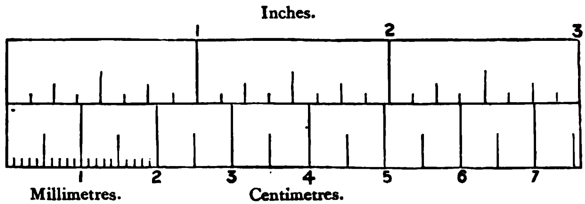
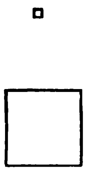
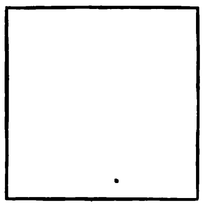
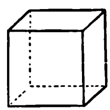
COMPARISON OF INCHES AND CENTIMETRES









A square millimetre above.
A square centimetre below.

A square inch.

A cubic centimetre.

I	metre	=	39.370 inches.
I	decimetre ($\frac{1}{10}$ metre)	=	3.937 inches.
I	centimetre ($\frac{1}{100}$ metre)	=	.393 inches.
I	millimetre ($\frac{1}{1000}$ metre)	=	.039 inches.

25.4	millimetres	=	I inch.
645	square millimetres	=	I square inch.
16,387	cubic millimetres	=	I cubic inch.

LIST OF REAGENTS USED IN THE PRACTICAL EXERCISES

Salt Solution — 0.6 per cent solution of common salt.

Lime Water. — Water saturated with lime (calcium hydrate) and filtered clear.

Acetic Acid. — Strong solution, and dilute (1 per cent) solution.

Hydrochloric Acid. — 0.2 per cent solution.

Sodium Carbonate. — 1 per cent solution.

Sodium Hydrate. — 5 per cent solution.

Copper Sulphate. — 5 per cent solution.

Iodine Solution. — 0.5 per cent of iodine and 2 per cent of potassium iodide.

Starch. — A very thin starch mucilage.

Carbonic Acid Gas, for the experiment with arterial and venous blood (page 108), may be obtained by the action of hydrochloric acid on chalk.

CHAPTER I

INTRODUCTION—CHEMICAL PRELIMINARIES

WHEN the body of an animal is examined it is seen at once to consist of many parts, more or less distinct from one another. These separate parts differ in form, in appearance, and in the way they are built up. Such differences are spoken of as differences in **structure**. The separate parts differ also in what they do, in the purposes they serve, in the use they are to the animal. Such differences are spoken of as differences in **function**. Parts that differ from one another in this way in structure and function are called **organs**. The liver, the stomach, the brain, the eyes, are examples of organs.

When any organ is examined it is found not to be of the same structure throughout its substance, but to consist of parts differing both in the materials of which they consist and in the building up of those materials. These different kinds of structural material are called **tissues**. Muscular tissue, nervous tissue, bony tissue, are examples of tissues. Some tissues contribute to the structure of several different organs; muscular tissue, for instance, occurs not only in what are specially called muscles, but also in the stomach, the intestine, the bladder, the eye, and in many other organs. When a tissue is examined with a microscope, it, in its turn, is found to consist of a number of units, **cells**, as they are called, built up together; and one tissue differs from another in the nature of its cells, and in the way they are connected together, just as one wall may differ from another wall in its bricks and in the way in which the bricks are laid.

The cells of the tissues of a living animal consist of living material, and this is sometimes called **protoplasm.**

When a tissue is examined chemically we find that many different chemical **substances** can be got out of it. The chemical substances make up the material of which it is composed. Albumin, sugar, fat, common salt, water, are examples of substances occurring in tissues.

Substances are either **simple** or **compound.** Compound substances are those that can be split up into, or can be shown to consist of, simple substances. Simple substances cannot be so split up. They are called **elements.** The body of an animal, then, is ultimately made up of elements for the most part united to one another to form compound substances.

About seventy elements are known to chemists, but only a few of these are found in the substances forming animal tissues. The chief elements found in the body are: oxygen, hydrogen, nitrogen, carbon, sulphur, phosphorus, chlorine, sodium, potassium, calcium, magnesium, iron.

Oxygen (O) is, under ordinary conditions, an invisible gas, and forms about one-fifth of the volume of the atmosphere. It supports combustion, and is necessary for the support of life. It forms eight-ninths of the weight of water, and is abundantly present in nature in combination with other elements. Oxygen is found as an element in the blood, and combined with other elements in a large number of the substances of the body.

Hydrogen (H) is a very light, invisible, combustible gas. When it burns in air it unites with oxygen, and water is formed. It forms one-ninth of the weight of water. It is found in combination with other elements in all animal and vegetable substances.

Nitrogen (N) is an invisible gas forming four-fifths of the volume of the atmosphere. A very small amount of nitrogen is found as an element in the blood. It exists in combination with other elements in very many animal and vegetable substances, and, as we shall see, then possesses its great importance.

Carbon (C) is a solid element existing in different conditions, as graphite, diamond, charcoal. It occurs in combination to a wide extent in nature; chalk and limestone, which form mountain ranges, consist very largely of carbon united with oxygen and lime. It occurs in all animal and vegetable substances.

Sulphur (S) is a solid element which exists in the free state near volcanoes, having been deposited from the volcanic gases. It is also found in large quantities in combination with other elements. Sulphur is present in combination in many animal and vegetable substances.

Phosphorus (P) is a solid, easily inflammable element, which is chiefly known in two varieties, one yellow and semi-transparent, and the other red. It does not exist free in natural substances. It occurs in combination in bones, and is obtained chiefly from bone ash.

Chlorine (Cl) is a greenish-yellow gas not found in nature in the free state, but occurring abundantly in combination. Common salt, present in large amount in sea water, is the most plentiful of its compounds. Much common salt is found in the body.

Air is a mixture of gases consisting of about four-fifths nitrogen and one-fifth oxygen, and a very small amount of carbonic acid gas. There is also present a varying amount of aqueous vapour, that is, water in the condition of a gas. The atmosphere exerts a pressure on everything it has access to. This pressure is equal to about 15 pounds on every square inch of surface.

The following are the chief metallic elements or metals, compounds of which are found in, and are necessary to, the animal body.

Sodium (Na) is a soft white metal existing in nature in large quantities in combination as rock salt, and Glauber's salt.

Potassium (K) is a soft metal like sodium, and like it exists in nature only in combination. Saltpetre and potash are compounds of potassium.

Calcium (Ca) is a metal occurring in combination in enormous masses in nature. Chalk, mountain limestone, marble, and plaster of Paris are compounds of calcium.

Magnesium (Mg) is a metal like calcium in many respects, occurring also abundantly in earthy compounds.

Iron (Fe).—Cast iron and steel consist almost entirely of the element iron. The element occurs abundantly in combination with earthy substances, as ores of iron. It is also present in the blood in combination with certain substances.

Compound substances are either **organic** or **inorganic.** The compounds which carbon forms with hydrogen, and generally with oxygen and nitrogen in addition to hydrogen, and occasionally with a few other elements also, are called organic compounds. They are so called because they were formerly supposed to be formed only by the agency of animal and plant life. All other compounds are called inorganic. These are said to be mineral in nature, and in a very large number of them a metallic element is present.

Water (H_2O) is a compound consisting of two parts by volume of hydrogen united with one of oxygen. A large amount of water occurs in all tissues of the body; in fact, the water present accounts for two-thirds of the body weight.

Ammonia (NH_3) is a compound gas consisting of three parts by volume of hydrogen united with one of nitrogen. It is commonly formed by the decay of animal and vegetable matter.

Carbonic acid gas (carbon dioxide) (CO_2) is a compound gas consisting of one part by volume of carbon united with two of oxygen. It is formed when carbon, or any substance containing carbon, such as coal, wood, oil, is burnt in air. It exists in the air, and is evolved from the earth by volcanoes. Carbonic acid is formed by living animals, and is present in the blood and tissues.

Carbon monoxide (CO) is a combustible gas formed by the incomplete combustion of carbon. It consists of one part of carbon united with only one part of oxygen. When it burns it forms carbonic acid gas. It is not found in the animal body.

The other inorganic compounds found in the body are those compounds called acids and salts.

Acids are compounds which hydrogen forms with certain other elements, most commonly non-metallic elements, and often with oxygen as well. Examples of acids are hydrochloric acid (HCl), formed by the union of hydrogen and chlorine, sulphuric acid (H_2SO_4), and phosphoric acid (H_3PO_4). Carbonic acid (H_2CO_3) is formed by the union of carbonic acid gas (CO_2) with water. Carbonic acid gas is generally called carbonic acid.

Hydrochloric acid occurs in the stomach. It is the only inorganic acid that is found free in the body.

Salts are compounds formed from an acid when the whole or part of the hydrogen of the acid is replaced by a metallic element or group of elements. Common salt is a salt formed from hydrochloric acid by replacing the hydrogen of the acid by the metal sodium, and is named sodium chloride ($NaCl$). Plaster of Paris is a salt formed from sulphuric acid by replacing the hydrogen by the metal calcium, and is named calcium sulphate, or sulphate of lime ($CaSO_4$). Common soda is a salt formed from carbonic acid by replacing the hydrogen by the metal sodium, and is named sodium carbonate (Na_2CO_3). Bone ash consists chiefly of a salt of lime formed by replacing the hydrogen of phosphoric acid by the metal calcium, and is named calcium phosphate, or phosphate of lime ($Ca_3P_2O_8$).

The chief salts found in the body are: sodium chloride, sodium carbonate, sodium phosphate, and in a smaller amount the corresponding salts of potassium; the sulphates of sodium and potassium, calcium carbonate ($CaCO_3$), the phosphates of calcium and of magnesium, and some salts of iron.

When the body of an animal is burnt the ashes consist of the salts of the body, the phosphate and carbonate of calcium being present in by far the largest amount.

The organic compounds of the body belong to the following groups: —

Proteids, which consist of carbon, hydrogen, oxygen, and nitrogen, united together in certain proportions with a small amount of sulphur. Albumin, fibrin, are examples of proteids. (They will be considered under *Food.*)

Carbohydrates, which consist of carbon, hydrogen, and oxygen united in certain proportions, but always containing twice as many parts of hydrogen as of oxygen. Sugar is an example of a carbohydrate.

Fats, which consist of carbon, hydrogen, and oxygen united in certain proportions, but always containing more than twice as many parts of hydrogen as of oxygen.

There are also present some organic acids and salts and many other organic compounds, of which important ones are urea (CON_2H_4) and uric acid ($C_5H_4N_4O_3$). (These will be considered under *Urine.*)

Physical Preliminaries

When a man does work or makes any muscular effort he is exerting what is called **force**. Similarly, force is exerted by any machine, apparatus, or thing which sets anything in motion, or brings to rest anything that was previously in motion.

When a force is exerted so as to move anything, the force is opposed, and is said to meet **resistance**. A cannon ball flying through the air meets no resistance (we here neglect the slight resistance of the air) till it strikes some object, and then, but not till then, does it exert force. A travelling steam-engine is exerting force against the resistance of the track and of the air. This resistance with that of the moving parts of the engine is tending to stop the engine, and when the steam is shut off will gradually stop it. The resistance is therefore a force. Thus one force is always opposed by another force.

When a weight is resting on a table it exerts a force on the table due to its tendency to fall, owing to the attraction of the earth, or **gravity**. The weight does not fall because it is opposed by an equal force — the resistance of the table. In this case the two forces are acting towards each other, and mutual **pressure** is said to be produced. If the weight is suspended by a string, the weight and the resistance act away from each other, and **tension** is said to be produced in the string. The resistance exerted by the surface of one thing to the motion of another thing moving over it, and in contact with it, is called **friction**. The rougher the surfaces, the closer the contact, and the greater the pressure between the two things, the greater will be the friction.

The **weight** of an object is the force with which the object is attracted to the earth. If a man is to raise a heavy object he must exert a force greater than its weight. When he has succeeded in raising the object he is said to have done a certain amount of **work**. All the time the man was attempting to raise the weight, he was exerting force, but until he moved it he had not accomplished any work. Work is performed only when some effect is produced. The power to do work which anything possesses is called its **energy**.

Heat is one of the forms which energy can take. When a man raises a weight some of the energy he expends in his muscles takes on the form of heat, while some is used in doing the work, and this portion of the expended energy remains in the raised weight, and confers upon the weight the power of doing just the same amount of work when it is let fall to its old position again. None of the energy the man expends is destroyed; part appears as heat and part remains in the raised weight. Just as material or **matter** may be changed into other matter but cannot be destroyed, so energy may assume different forms, such as heat or light, or be stored in the object on which work is done, but cannot be destroyed.

The energy which appears as heat passes away from the man to the things around him, both to the things in contact with him, by **conduction**, as it is called, and by passing through space to things away from him, by **radiation**, as it is called. The energy is by these and other means scattered and rendered unavailable for doing work though it is not destroyed; it is said to be **dissipated**.

CHAPTER II

OXIDATION—LIFE—PLANTS AND ANIMALS

A MAN who is alive differs from a man who is dead inasmuch as he is constantly performing movements, not necessarily of his whole body from place to place, or even of his limbs, but movement of his chest, by which air is drawn into his body, and movement of his heart, by which blood is circulated throughout his body. So long as these two movements go on the man is alive; when they have both stopped the man is dead. A certain amount of force is required to suck air into the lungs and to pump blood throughout the body; that is, a certain amount of energy has to be used to do this work. When a man is doing manual labour a large amount of additional energy is being used to accomplish the work he has to do. Thus whether the man is at rest or at work, energy is being expended so long as he is alive.

A piece of coal consists of carbon and hydrogen united with one another and with other elements to form complex chemical substances. If a piece of coal is lighted, the carbon and hydrogen are separated by the breaking up of the complex arrangement of elements, and unite with the oxygen of the air to form carbonic acid and water. This breaking up of the complex substances of the coal by the union of the carbon and hydrogen with oxygen sets free energy, kinetic energy, as it is called, in the form of heat and light, and so intense is the heat that we say the coal "burns." The energy thus set free may be used in many ways to do work as it is in a steam-engine. Energy existed in the coal before it was lighted, having been stored up as "latent energy" when the elements were knitted together into complex compounds by the growth of the living tree in a past age. Generally speaking, when elements or simple compounds are united into complex compounds, energy is stored up, and when oxidation takes place and these compounds are broken down into simpler compounds again, such, for instance, as carbonic acid and water, the energy is again set free.

The dead body of an animal also consists of substances formed by the union of carbon and hydrogen and other elements into very complex compounds. If the dead body be burnt, oxygen unites with these elements, oxidation takes place, carbonic acid and water are formed, and only a small amount of incombustible material remains, just as in the case of coal the ashes remain. The heat given out when the body is burnt is the energy set free by the oxidation of the complex chemical substances. The dead body and the piece of coal give out no energy or heat till oxidation takes place, and till then they are as cold as other things around them.

The living body of an animal consists of the same complex substances as a dead body, but it differs from the dead body in being warm, and usually warmer than the lifeless things around it. It is warm because it is constantly giving out energy as heat. The complex substances of the living body are constantly breaking down, and their oxidation is constantly taking place, forming in the same way carbonic acid and water. The breaking down of the complex substances and the oxidation in the living body are, however, taking place gradually, so that the energy is set free little by little, and therefore the amount of heat given off at any one time is small. Thus the temperature produced is only a little above that of surrounding objects, while the oxidation which takes places when the dead body is burnt is sudden and intense, and so a high temperature is produced. A high temperature is produced when a dead body is burnt because all the energy stored up is given out in a very short time. When the dead body of an animal decays, an extremely slow oxidation of the substances composing the body goes on; carbonic acid, water, and ammonia are formed, and mostly pass away, until almost the same remnant is left — the ashes, just as if it had been burnt. The energy it gives off during the slow process in the one case is much the same in total amount as that given off all at once to form the white heat of the flame in the other case.

The coal can only burn where it is in contact with the air, for only the particles on the surface of the piece can get oxygen. There are no means by which oxygen can get freely into the piece of coal so that the particles inside the solid mass can be oxidised at the same time as those at the free surface. All the parts of a living body, on the other hand, are slowly taking up oxygen and giving out energy at the same time. Every one of the living particles, the fundamental units, or **cells** of the body, has oxygen brought to it. The two movements, those of the chest and of the heart, by the presence of which we recognise that the animal is living, have for one of their chief purposes the bringing of oxygen to all the cells of which the animal's body is formed. By breathing, air is brought almost into contact with the blood in the lungs, and by the blood oxygen is taken from the air, and then the blood thus charged with oxygen is driven by the heart to the cells.

The burning coal gives out all its energy in the form of heat. An animal, on the other hand, even when not moving its body or limbs, uses some of the energy resulting from the oxidation of its living cells to do work, namely, the work concerned in the movements of respiration and circulation. When the animal has for a time to do heavy work the energy given out by the living body is for the time greatly increased, both the part which is expended in doing work, and the part which is given out as heat. The burning coal, on the other hand, cannot thus change the amount of energy it is to give out at any time.

Waste and Renewal. — The complex substances forming each cell are then constantly breaking down into simpler compounds, of which the simplest and final ones are water and carbonic acid, and are setting free a certain amount of energy. Each cell must therefore gradually waste away if it does not get more of the complex substances of which it is formed. In the same way the total of the cells, that is, the animal, does, as we know, waste away if it cannot get food. From the food which the animal eats certain substances are carried to each cell, by the blood, from the stomach and intestines. From these substances, brought to them by the blood, the cells can build up the complex substances of which they are themselves composed. This power which cells have, on the one hand, slowly to break up their own complex substances and to undergo oxidation, and so to give out energy, and, on the other hand, to build up again more of their own substances from simpler substances, belongs to living matter alone. It is the possession of this double power of breaking down and building up which constitutes life.

Physiology is the study of the means by which these processes are carried out in the cells and in the body as a whole, and of the modes by which the energy liberated is used by the animal for various purposes.

Plants and Animals compared. — Plants as well as animals consist of living cells, and have in common with animals the properties essential to living matter, namely —

1. They are constantly building up living matter and complex substances from simpler substances, and so storing up energy.
2. They are constantly taking up oxygen and undergoing oxidation, and so breaking down living matter.
3. They form new plants or animals like themselves.

Plants require oxygen for their life, just as animals do, but their oxidation goes on much more slowly. In plants, the building up of complex substances is far in excess of their breaking down. A tree, as a rule, goes on growing all the time it lives, and when it dies leaves a mass of complex substances, and from them a large amount of energy may be obtained when these substances are, as by the burning of the tree, oxidised into simpler substances again. On the other hand, in an adult animal, an animal no longer growing, the breaking down of the complex substances goes on as fast as the building up of the new.

Plants are able to do what animals cannot. A plant can build up its living matter and form the complex substances of which it consists by obtaining the elements it needs from very simple chemical compounds. All green plants obtain carbon from the carbonic acid gas of the air, and the other elements they require from simple chemical compounds in the soil. Most of these compounds are mineral or inorganic compounds. Animals, on the contrary, cannot live on inorganic substances; they can build up their living matter only from the peculiar complex substances which plants form, and which are spoken of as organic. Animals can live only on plants or on the substances of which other animals consist, substances which have themselves been formed from plants.

Animals are able to do freely what plants rarely do, or do to a slight degree only. An animal can move; either the animal can move its body from place to place, or, if fixed, can move some of its parts relatively to its other parts. Moreover, it can apparently move of its own accord. It is said to be automatic. Again, an animal responds to influences exerted on it. If it is disturbed it will move, or if it is interfered with when it is moving, it will stop moving, or move faster, or move in some different way. These are familiar properties of animals, but are only rarely seen in plants.

CHAPTER III

GENERAL STRUCTURE OF THE BODY

PROCURE a rabbit which has been recently killed, but not skinned. Fasten the rabbit on its back by its four limbs to a board, and then, with a small sharp and pointed knife and a pair of scissors, all the dissection necessary for this lesson can be made.

The **body** of the rabbit, like that of a man, consists of head, trunk, and limbs. The fore or anterior limbs, and the hind or posterior limbs, like the arms and legs of a man, are divided by joints into three main parts. The parts of the fore-limb correspond to parts of the hind-limb. Using the terms applied to the human body, the arm, the forearm, and the hand of a forelimb correspond to the thigh, the leg, and the foot of a hind-limb. The head consists of the skull and the face, and is connected to the trunk by the neck.

The larger hinder or lower part of the trunk, called the **abdomen**, is soft and yielding when handled. The smaller front or upper part of the trunk, between the forelimbs, called the **thorax**, is firm, less yielding, and changes its shape a little only on being handled. In the sides of the thorax, bones, the **ribs**, passing from the back towards the front, can be distinctly felt. In the front of the thorax, in the middle, is the firm bone, the **sternum**, to which the ribs pass. The posterior or lower end of the sternum is quite distinctly felt, because it projects beyond the ends of the last pair of ribs joined to it. If the back of the rabbit is handled, the vertebral column or **spinal column**, a chain of bones, which can be bent to a small extent

FIG. 1. — The viscera of a rabbit as seen upon simply opening the cavities of the thorax and abdomen.

A, Cavity of the thorax; *B*, diaphragm; *C*, ventricles of heart; *D*, auricles of heart; *E*, artery to lungs; *F*, aorta; *G*, lungs, collapsed; *H*, part of pleura; *I*, cartilage at end of sternum; *K*, portion of body wall left between thorax and abdomen; *a*, cut end of ribs; *L*, liver, in this case lying more to the left than to the right of the body; *M*, stomach; *N*, duodenum; *O*, small intestine; *P*, cœcum; *Q*, large intestine.

in various directions, may be felt running down the middle from the head to the tail.

Cut through the skin, and only the skin, of the thorax and abdomen in the middle line, turn it back on each side, dividing it in one or two places so that the front of the animal is laid bare. Stretching from the sternum and the upper ribs to the forelimb on each side is a large mass of flesh or **muscle**. Cut through this muscle on each side close to the sternum, and turn it outwards towards the limb. The ribs and sternum will then be distinctly seen. They are greyish in colour, and consist of bone. The ribs at their front ends before they reach the sternum suddenly become white in colour, and softer to the touch. These ends do not consist of bone, but of **cartilage**. The lower end of the sternum forms a thin plate which consists also of cartilage. See that the ribs can be traced back to the vertebral column. Between them, and connecting them to one another, are muscles, the intercostal muscles.

The abdomen is still closed by, in addition to the skin, a thin wall made up of thin sheets of muscle on each side, which meet in the white line running down the middle. This white line is of a fibrous nature, called **tendon**. There is often a good deal of fat lying just underneath the skin, and covering the thin muscular wall of the abdomen. The muscular wall of the abdomen extends backwards on each side to the vertebral column, and downwards to the hip bones, from which the lower limbs arise.

Carefully cut through the wall of the abdomen in the middle line from the lower end of the sternum downwards, and make one or two transverse cuts in the wall on each side, so that the contents of the abdomen are well seen. Raise the lower end of the sternum, and gently draw down the organs or viscera, which lie just below it; you will then see a partition, which is thin and almost transparent in the middle, stretching right across the body, and completely separating the abdomen from the thorax. This partition is the **diaphragm**.

Without disturbing the viscera at all, the following organs will be seen in the abdomen: —

1. The **liver** (*L*). A dark-red mass, in several parts, called lobes, situated immediately below the diaphragm, with the gall-bladder which appears green on its front edge.

2. The **stomach** (*M*). A greyish-white organ, situated directly below the diaphragm, but more on the left side of the rabbit than the liver, by which it is partly covered.
3. The **duodenum** (*N*). Part of the small intestine. A reddish-white tube, lying at the right of the stomach, close to the liver.
4. The **ileum** (*O*). Part of the small intestine. A dark greyish tube, lying in many turns, occupying a large part of the middle of the abdomen.
5. The **cœcum** (*P*). Part of the large intestine. A large tube, much darker in colour than the small intestine, lying below them, across the abdomen, in a few coils.
6. The **colon** (*Q*). Part of the large intestine. A smaller tube than the cœcum, lighter in colour, and of a puckered appearance, seen at the lower end of the cavity.
7. **Bladder.** A thin-walled bag lying in the middle line at the bottom of the abdomen, varying in size, and therefore more or less seen according to the quantity of urine it contains.

Draw out one of the coils of the small intestine. Passing from its border is a thin transparent membrane, the **mesentery**. This membrane attaches the intestine along its whole length to the vertebral column at the back of the abdomen. In the mesentery, **blood-vessels** are seen, which branch as they pass along the mesentery to the intestine. Cut or tear through the mesentery close to the intestine, and go on until you have unravelled all the small intestine, gradually turning it out of the abdomen as you proceed. In doing so the blood-vessels will be torn, and the **blood** in them will escape. You will find that the small intestine is a long tube, connected at one, the lower, end to the cœcum, and so to the rest of the large intestine, and at the other end by means of its upper portion, the duodenum, to the right end of the stomach. Turn out the cœcum and rest of the large intestine down to its lower end, where it is fixed at the place where the tube, the lower part of which is the **rectum**, opens to the exterior of the body, at the anus.

The duodenum is more firmly fixed by the mesentery than the rest of the small intestine. In this part of the mesentery is situated a large, but thin and irregular, greyish-white organ, the **pancreas**. The pancreas, then, lies to the right of and below the stomach in the mesentery fixing the duodenum. In moving the small intestine you will have seen a small dark-red organ, about two inches long, which was lying just below the left end of the stomach, and partly covered by the intestine. This is the **spleen**.

Under the intestines, a little above the middle of the abdomen, on each side of the vertebral column, is a dark-red organ, about 1½ inch long, partly covered with fat. This is the **kidney**. Passing from the inner side of each kidney is a fine whitish tube, the **ureter**, which runs downwards to the bottom of the abdomen to the bladder, lying in the middle line in front of the rectum.

Cut across the intestine, and lay it open a short distance along its length, to satisfy yourself that it is a tube. Open the duodenum in the same way, to see that its cavity opens out of the cavity of the stomach. Open the stomach by a cut from side to side along its lower edge, and turn out its contents, which consist of partly-digested food. At the upper left-hand part of the stomach is the opening into it of the **œsophagus**, a tube which passes from the mouth down the neck, through the thorax, and piercing the diaphragm, enters the stomach. By means of this tube the food reaches the stomach. There is thus a continuous tube from the mouth, by means of the œsophagus, stomach, and intestines, to the anus. This tube is called the **alimentary canal**, because it is for the alimentation or feeding of the body.

Cut through the ribs and muscles between them on each side of the thorax, beginning at the lower end, and lay open the thorax by removing the middle piece, lifting it up at its lower end first. A little on the left of the middle, enclosed in a thin bag, called the **pericardium**, is the **heart**. Slit open the pericardium, and so lay bare the heart — a conical, muscular organ, with the pointed end below and the broad end above. Gently tear away the fat covering the broad end or base, where several tubes, called **arteries** and **veins**, are connected with the heart. The tube which looks the largest, feels the firmest, and is whitish in appearance, is an artery, the **aorta**, which carries the blood from the heart to the different parts of the body.

Leading up to the heart from below, deep in the thorax, is a dark reddish purple coloured vessel, a vein, the **inferior vena cava**, which brings the blood from the lower limbs and lower part of the trunk, through the diaphragm, back to the heart. Above the heart there is another large vein, made up by several branches, which brings the blood back from the head and upper limbs. This is the **superior vena cava.**

In the thorax, on each side of the heart, is a soft, pinkish, spongy organ; this is the lung. The **lungs** are attached to the vertebral column just under the heart, and by arteries and veins to the base of the heart, but are otherwise free, and not connected to the walls of the thorax. Each appears much smaller than the half of the thorax in which it lies. The lungs have collapsed, but when the animal was alive each lung was filled and distended with air, and filled its side of the thorax. Cut out a bit of one lung, notice how soft and light it is; it still contains some air, and if put in water will float.

Make a cut downwards through the skin of the neck, exactly in the middle line. Running down the middle of the neck is a tube (partly covered by muscles, which should be cut away), easily recognised, because there are a number of rings of cartilage round it all along. This tube is the **trachea.** After the trachea reaches the thorax, it divides into two branches, one passing to each lung. Slit the trachea open with scissors, and in this way trace it upwards. A little above the middle of the neck it widens out into a box-like cavity, with walls of cartilage, the **larynx.** The larynx opens above by a slit-like opening into a wide space, the **pharynx,** which is continuous with the mouth. Air from the mouth can pass through the larynx into the trachea, and so to the lungs. Pass a penholder from the pharynx downwards behind the larynx; it will pass into a tube lying underneath the trachea. This is the œsophagus, leading to the stomach.

Remove the skin from one of the hind limbs. Notice that the fleshy part consists of **muscles,** running mostly lengthwise, which can be more or less easily separated from one another. Each muscle is fixed at its two ends, and some of them along the deeper edge as well. They are fixed to bones. The ends by which the muscles are fixed are whitish, tough, and fibrous; these are **tendons.** Between the muscles are blood-vessels, and delicate white cords, which branch as they pass down the limb. These latter are **nerves**. The muscles, vessels, and nerves are lightly bound together by a delicate tissue lying between them, and passing from one to the other. This is called **connective tissue**.

Strip away the muscles from the bones of the thigh and leg. The bone of the thigh is connected to those of the leg by means of bands of firm tissues, very like tendons in nature, called **ligaments**. The ends of these bones, kept in place by the ligaments, fit into each other to form a hinge-like joint. The upper end of the thigh bone is rounded and ball-like, and fits into a socket in the hip bone, and is kept in place in the same way by ligaments. Free the muscles from the vertebral column. The vertebral column, along its whole length, from the skull to the pelvic girdle, is made up of a number of bones, **vertebræ**, joined one to another by ligaments. To each vertebra in the thoracic region is attached a rib.

Break across the vertebral column, and you will see the white, soft **spinal cord** which runs along inside the vertebral column. Separate a single vertebra. It consists of a solid body, with a ring-like arch, on the dorsal side, or side which was towards the back. The bodies of the vertebræ lie on one another, and the arches lie on one another, so that when the latter are together they form a canal. In this canal the spinal cord lies. The spinal cord is continuous above with the **brain**, which is enclosed by the skull. From the brain and spinal cord the nerves going to all parts of the body arise.

The Cavities of the Trunk and their Organs in Man

The Walls of the Abdomen. — In a man the walls of the abdomen and of the thorax are formed in the same way as in a rabbit, but it will be well to consider more carefully the boundaries of these cavities, and the position of the organs they contain as they are in ourselves. At the top of the abdomen lies the diaphragm, the arched partition separating it from the thorax; at the back is the vertebral column and muscles of the loins; in front and at the sides are the sheet-like muscles of the flanks and of the anterior wall, and below is the pelvis or girdle of bone formed by the two hip bones, to which the thigh bones are attached. Of the sheet-like muscles there are three placed on one another, and all united together into a white band of tendon running down the middle of the anterior wall. On each side of this white band there is a narrow band-like muscle running parallel with it. Thus the front and side walls of the abdomen are made up by four distinct muscles on each side of the middle line, these being covered by a layer of fat, and then by the skin. The inner side of the layer of muscles is covered by a thin transparent membrane, called the **perito-**

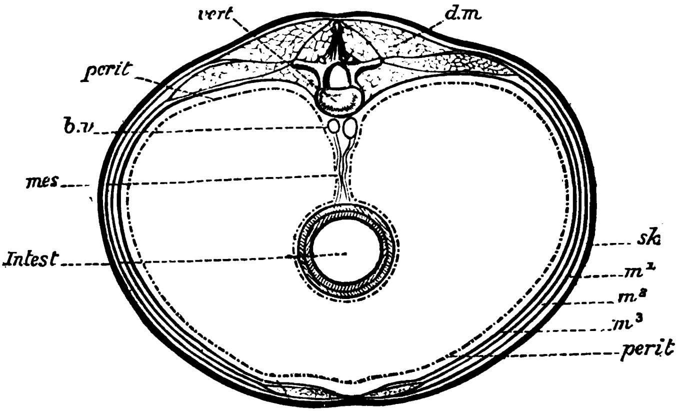


FIG. 2. — Diagram to show how the wall of the abdomen is made up, and how the mesentery supports the intestine.

The body is supposed to be cut across, and the intestine is represented as the section of a straight tube. In reality the space between the intestine and the body wall is filled by the coils of the intestine and by other organs.

Vert, vertebra; *d.m*, muscles of back; *sk*, skin; m^1, m^2, m^3, the three muscle layers; *perit*, peritoneum; *mes*, mesentery; *intest*, intestine; *b.v*, blood-vessels.

neum. This membrane covers also the muscles and spinal column at the back, and the under surface of the diaphragm above, as well as the pelvic bones and muscles on the inner side of the pelvic bones below, forming, in fact, a continuous and closed lining for the abdominal cavity. From the vertebral column the peritoneum passes out into the cavity of the abdomen as a thin transparent sheet, the mesentery, which, as we have seen, fixes and supports the intestine.

Situation of the Abdominal Organs. — The liver is situated on the right side, close under the arch of the diaphragm.

The stomach is on the left side, just under the diaphragm.

The duodenum, or first portion of the small intestine, leaving the stomach at its right end, lies close to, and just below the

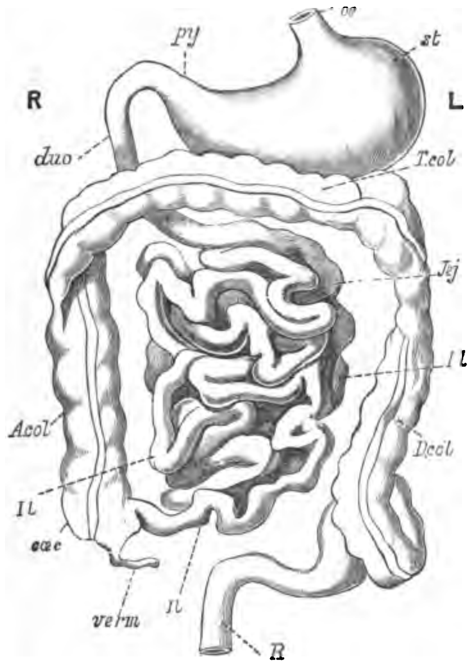


Fig. 3. — The alimentary canal in the abdomen.

R, right; L, left; *œ*, œsophagus; *st*, stomach; *py*, pylorus; *duo*, duodenum; *Jej*, jejunum; *Il*, ileum; *cæc*, cœcum; *A.col*, ascending colon; *T.col*, transverse colon; *D.col*, descending colon; *R*, rectum.

liver; it is about ten inches long, and passes first towards the right, then downwards, and then to the left, and so forms a loop or bend.

The small intestine forming the continuation of the duodenum is thrown into coils, which lie chiefly in the central and lower parts of the abdomen. The part next to the duodenum is a little redder (there being more blood-vessels in it) than the rest; this is called the jejunum. The remaining part of the small intestine is called the ileum. At the lower part of the abdomen, on the right side, in the right groin, it opens into the large intestine. The whole length of the small intestine is about twenty feet.

The large intestine is much broader than the small intestine, and is thrown into puckers. It begins in the right groin, in a dilated part called the cœcum. The small intestine opens into the cœcum, and at the opening there are two folds of tissue, which form a valve, so that matter can pass readily from the small intestine into the large intestine, but not back again. This valve is called the ileo-cœcal valve. There is a small structure growing out, as it were, of the cœcum at its lower end; this is called the vermiform appendix. The large intestine is continued from the cœcum up the right side of the abdomen nearly to the liver; it then turns and runs across just below the stomach, and then runs down the left side; these three portions are called the ascending colon, the transverse colon, and the descending colon. The descending colon passes on by a straight tube, about nine inches long, called the rectum, which ends at the external opening or anus. The large intestine, including the rectum, is about six feet long.

The pancreas lies, supported by the mesentery, in the bend of the duodenum. It is about seven inches long, and lies transversely just below the stomach; it is covered in front by the transverse colon, and partly by the stomach. Its right end, round which the duodenum bends, is thick, and called the head; the left end is thin, and called the tail.

The spleen lies under the stomach, on the left side, just to the left of the tail of the pancreas.

The kidneys are situated deep in the abdomen, one on each side of the vertebræ of the loins. The one on the right side is close under the liver, and the one on the left is close under the spleen.

The bladder is situated at the lower end of the abdomen, in front and in the middle line. The rectum passes behind it.

The Walls of the Thorax. — Below lies the diaphragm; at the back is the vertebral column, with the ribs arising from it, and the muscles of the back; at the sides are the ribs and the intercostal muscles between them; in front is the sternum and the ribs with their cartilaginous ends meeting it; above, the thorax is closed by the upper ribs gradually becoming shorter, the first rib being a small flattened arch, which forms, with the muscles at the root of the neck, the upper limit of the cavity.

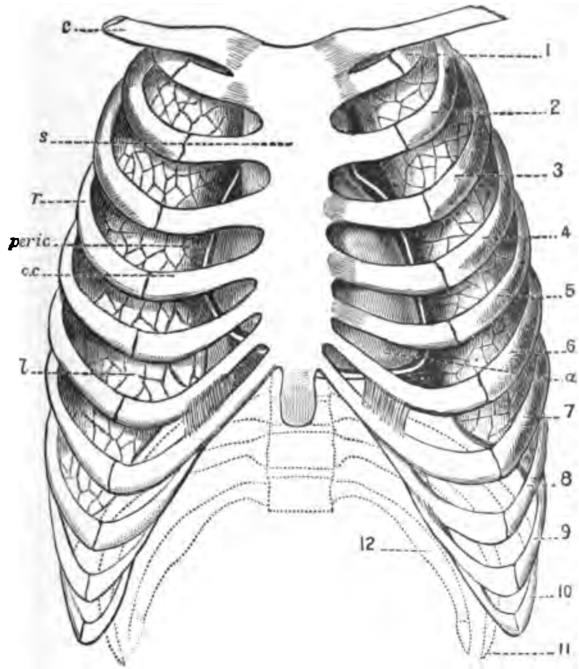


FIG. 4.— Diagram of the thorax showing the position of the heart and lungs. 1–12, ribs; 11, 12, floating ribs. *s*, sternum; *r*, rib; *c.c*, costal cartilages; *c*, clavicle; *l*, lungs; *a*, apex of heart; *peric*, pericardium, cut edge.

The wall of the thorax is also covered by large muscles passing both from the back and from the front over the sides of the chest to the arms. Over these muscles is a little fat, and then the skin.

Lining the inner surface of the wall of the thorax is a thin membrane, called the **pleura**, like the peritoneum lining the inner surface of the wall of the abdomen. The pleura is, however, in two parts, one for each side of the chest, with the heart between the two.

Situation of the Thoracic Organs. — The lungs are situated one in each lateral half of the chest; each is quite free and separate from the wall except at one place, where it is fixed to

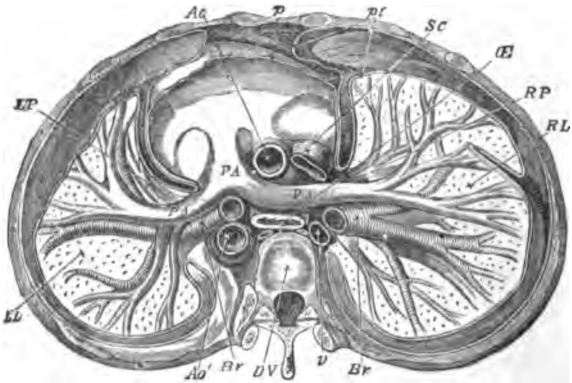


FIG. 5. — **Diagram of a transverse section of the chest showing the heart and lungs in place.**

DV, dorsal vertebra; *Ao*, aorta; *Ao'*, part of aorta descending to abdomen; *SC*, superior vena cava; *PA*, pulmonary artery dividing into a branch for each lung; *LP*, *RP*, left and right pulmonary veins; *Br*, bronchi; *RL*, *LL*, right and left lungs; *Œ*, œsophagus; *p*, pericardium; *pl*, the two layers of pleura; *v*, a vein. A space, shaded, is represented between the two layers of pleura; such a space does not in reality exist.

the vertebral column; this is just where the vessels from the heart and the tube from the trachea go into it. Now the pleura on each side lines the whole wall of the chest, except where each lung is fixed to the vertebral column, for where it meets the root of the lung, as this is called, it passes over the whole surface of the lung, forming a kind of bag for it; in fact, it is chiefly the pleura which in this way fixes the lung to the vertebral column. This layer of the pleura over each lung is closely adherent to the tissue of the lung, and cannot be separated from it; it is this which gives the lung its smooth and shining appearance. Between the layer of pleura on the lung or visceral pleura and the layer of pleura on the wall of the thorax or parietal pleura there would be a space if each lung did not entirely fill each lateral half of the thorax. This it does, for during life each lung is distended with air till the pleura on its surface meets the pleura on the wall of the thorax, leaving only enough room for a very thin layer of fluid, just enough to keep the surfaces of each layer of the pleura moist so that they can slide easily on each other.

The heart is placed obliquely across the front of the thorax. Its base is just underneath the sternum, at the level of the third rib, and it extends downwards and towards the left, so that the apex is situated between the fifth and sixth ribs on the left side. The apex touches the chest wall, and the beating of the heart can be easily felt through the intercostal muscles between these two ribs. It is generally most distinct about one inch below and half an inch to the inner side of the left nipple.

CHAPTER IV

THE BLOOD

Nature of the Blood. — The blood is a liquid with a large number of minute solid bodies floating in it. The solid bodies, the **corpuscles**, are of two kinds — the red and the colourless. There are about 5,000,000 red corpuscles in a cubic millimetre[1] of blood, and there are about 500 times as many red corpuscles as colourless corpuscles. The colour of the blood is due to the red corpuscles in it. The liquid in which the corpuscles lie, the **plasma**, is water, containing a number of substances in solution; so that it is "thicker" than water, and since the corpuscles are only a very little heavier than the plasma, they will not easily settle. By a method which will be described later on, they can be made to settle, and the plasma is then seen to be almost without colour, having only a pale yellow tint.

The Red Corpuscles. — When a drop of blood is examined with the microscope the red corpuscles appear of a reddish-yellow colour, and the plasma in which they are lying appears quite colourless. A red corpuscle is round and flat like a coin, but thinner in the middle than near the edge, so that each side is slightly concave. They are all about the same size, $\frac{1}{3200}$th of an inch across, and about a quarter of that in thickness. They are very numerous, so that they are often too crowded together to be studied carefully, and they are prone to run face to face into rows like a pile of coins. Some will be rolling over, so that they will be seen on edge; others will be seen on the flat. In the latter case they will be darker or lighter in the centre, according to the focus of the microscope. They are soft and

[1] See p. xi.

flexible, changing their shape as they are carried by the currents against one another, and, being elastic, immediately resume again their previous form. On account of these properties they can be forced through spaces which are smaller than their usual diameter. The elastic substance of which they consist, called **stroma**, is of a close-set, spongy structure, and holds the red colouring matter which is called **oxyhæmoglobin**. The oxyhæmoglobin can be dissolved out of the corpuscles, and the stroma is then left as a colourless framework. If blood is diluted with water, the stroma takes up more and more water, till the corpuscle swells out and becomes spherical. If salt is added to the drop of blood, water passes out of the meshes of the stroma, and the corpuscle becomes shrunken and wrinkled.

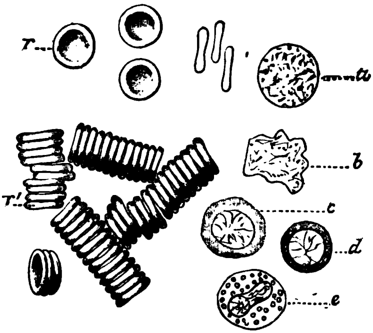


FIG. 6. — Blood corpuscles.

r, red corpuscles seen on the flat; *r'*, red corpuscles seen on edge, and run together into rows; *a*, *b*, colourless corpuscles, nucleus not seen; *c*, *d*, *e*, colourless corpuscles, nucleus seen; *e*, containing also granules.

The Colourless Corpuscles. — The colourless corpuscles, unlike the red corpuscles, vary much in size, but most of them are larger than the red, being about $\frac{1}{2500}$th of an inch in diameter; some are as small as, or even smaller, than the red. They must be looked for carefully, since they are devoid of colour and scanty. Some are globular in shape, and are crowded with granules; others are very irregular in outline, and are constantly changing their shape so long as they are alive. They remain alive for a short time in a drop of blood on a slip of glass, and are active in changing their shape, especially if the glass is kept just warm. The red corpuscles only change their shape through pressure on them, as they are forced against obstacles by the blood stream. The colourless ones, on the other hand, are active of themselves, and, being more adhesive than the red, are often seen fixed in one spot, changing their shape apparently of their own accord. This kind of movement is called amœboid, because it is well seen in a simple organism called an Amœba, met with in stagnant water. A colourless corpuscle is a cell, the substance of which is different from the stroma of a red corpuscle, and is often spoken of as protoplasmic. In this protoplasmic cell-substance, which is living material and consists chiefly of proteids, united with water, salts, and certain other substances, are embedded a number of granules, and generally nothing more is seen but a small mass of granular or cloudy material. If water or

FIG. 7.—Changes of form of a colourless corpuscle in a few minutes.

very dilute acetic acid (vinegar) be added, the cell-substance becomes clear, and in it there is brought to view a rounded or irregularly-shaped body, which is darker than the rest of the cell. This body is called the **nucleus**. The nucleus is brought to view because the acid has dissolved the granules which were hiding it. The colourless corpuscles are then nucleated cells, and this is the case in all animals. The red corpuscles of man have no nucleus, and this is true of all the higher animals, those that suckle their young; but the red corpuscles of birds, reptiles, and fishes have a large oval nucleus.

If a drop of the blood of a frog is examined with the microscope the red corpuscles will be seen to be much larger than those of man, and to be oval and biconvex and to have nuclei. The white corpuscles of the frog are about the same size and of the same structure as in man.

Clotting of the Blood.—Get a butcher to allow you to catch the blood from an animal which he is killing into two separate basins. Put one basin aside, and allow it to stand undisturbed. Stir sharply the blood as it is flowing into the other basin with a rough stick or bundle of twigs and keep on stirring it for three or four minutes. When the blood in the first basin is firmly set, which it will be in from fifteen to twenty minutes, the two lots of blood may be taken away for subsequent observation.

Blood freshly drawn is perfectly fluid. After it has been standing for two or three minutes it becomes "thick" or viscid; this will be readily noticed if the basin containing it is tilted. Three or four minutes later still the whole sets to a jelly, and this jelly becomes subsequently so firm that the vessel if small can be turned upside down without the blood falling out. After a time, it may be an hour or more, a few drops of a yellow fluid seem to have oozed out from the jelly-like mass, or clot. The surface of the clot will be concave, because while it is shrinking, its edges adhere at first to the sides of the basin. Gradually more and more of the yellow fluid, **serum**, collects at the top and sides. The serum is squeezed out of the clot as the clot goes on shrinking, until at length there is a considerable amount of serum with a red clot lying in it.

If a drop of the serum be carefully removed and examined with the microscope, no red or even colourless corpuscles will be found in it. If a particle of the clot be flattened out and examined in the same way, crowds of red corpuscles and some colourless ones, with a close meshwork of fine threads binding them together, will be seen. The close meshwork consists of fine fibrils of a substance called **fibrin**. The clotting of the blood, as this process is called, leads then to the formation of a fluid, serum, and of a clot consisting of fibrin and the red and colourless corpuscles.

When blood, as sometimes happens, is a long time in clotting, some of the corpuscles have time to sink, and since the red ones sink more easily than the colourless ones, the uppermost layer of the clot is formed chiefly of colourless corpuscles, and hence is lighter in colour than the rest of the clot. This layer is called the buffy coat.

If fresh blood is rapidly stirred with a bundle of twigs, as directed above, the threads of fibrin as they form are caught up and cling to the twigs; and as the formation of the fibrin goes on the threads become matted upon the twigs, and so, after the stirring has been continued for three or four minutes, all the fibrin which can be formed will be formed, and will have been caught up and collected on the twigs. If the twigs are then washed in a stream of water, nearly pure fibrin will be obtained. Fibrin is a colourless, soft, stringy, elastic substance. The blood which is left after being thus whipped will not clot again, however long it be allowed to stand, because all the fibrin it could make has been removed. It is still red in colour, and examined with the microscope is seen to contain red and white corpuscles like ordinary blood.

If a strong solution of common salt or of Epsom salts be added to fresh blood, and especially if the mixture be then kept cold by ice, the blood will not clot for several days, or not at all. As it stands, the corpuscles will gradually settle and leave a little clear plasma at the top. If some of this plasma is carefully drawn off the top by a glass tube and taken out of the cold, and especially if a little water is added to it to dilute the salt put in, it will go into a jelly, and this will lead in a short time to a colourless clot and a little serum. The serum formed by the clotting of plasma is exactly the same as the serum formed by the clotting of the whole blood; but the clot consists only of fibrin, and has no red or colourless corpuscles entangled in the fibrin. This experiment shows that the clotting of blood may take place without the corpuscles. It is the plasma which forms the fibrin.

Composition of Serum. — Serum is a yellow alkaline fluid consisting of water holding proteids, salts, and other substances in solution. There are two proteids present in serum called respectively **albumin** and **globulin.**

The white of egg consists chiefly of albumin, and the albumin of the serum is very like, although not quite identical with, the albumin of the egg. When the egg is boiled the albumin "sets" and becomes solid, white, and opaque, and in the same way if some serum is heated it becomes white, opaque, and nearly solid, due to the "setting," or coagulation as it is called, of the albumin in the serum. The proteid globulin also coagulates in the same way when the serum is heated, so that this also contributes to the result. Globulin differs from albumin in that while albumin is soluble in mere water, distilled water, globulin is only soluble in water containing certain salts; these salts are present in serum, hence globulin is present in serum in solution. After they have been coagulated by heat, they are both like boiled white of egg, not soluble at all.

Composition of Plasma. — Plasma differs from serum in containing in addition to albumin and globulin, a third proteid which is called **fibrinogen**. Fibrinogen is very like the globulin of serum (serum globulin, or paraglobulin as it is sometimes called), but differs from it in being coagulated at a lower temperature. It solidifies and turns white at 56° Centigrade (132° Fahrenheit), while the serum albumin and serum globulin do not coagulate till the temperature is raised to about 75° C. (167° F.). Fibrinogen is the substance in the plasma which changes into the solid fibrin during the clotting of the blood.

When the blood is shed, some of the colourless corpuscles break up and discharge into the blood a peculiar substance called **fibrin ferment**. The presence of a very little of this substance so influences the fibrinogen as to make it able to turn into fibrin.

The Salts of the Blood. — Salts are present in the plasma and in the serum in small quantity, less than 1 in 100 parts. They are chiefly carbonates, chlorides, and phosphates of sodium and potassium, with salts of calcium and magnesium in smaller quantity. The blood is alkaline, due to the alkaline salts it contains.

During the clotting of the blood the fibrinogen probably takes up some of the calcium of the plasma in becoming turned into the new substance, the fibrin.

Observation of the Circulation of the Blood

The blood carries to the tissues all the nourishment which these require. The cells of which the tissues consist get all the material they require for the building up of their own substance and the oxygen they need for their life from the blood, and give to the blood the waste substances and the carbonic acid which they cast off. In order to bring to the tissues a proper supply of food, the blood must pass through the organs which receive the food the animal eats; it must also pass through the lungs to get oxygen from the air; and in order to get rid of the waste substances, it must pass through the organs whose function it is to remove these. We thus see the necessity for the circulation of the blood.

The circulation of the blood can be easily seen in the web of the frog's foot. The frog is a most useful animal for studying physiology. Its value depends chiefly on its being what is called a "cold-blooded" animal, that is, an animal whose temperature varies with the temperature around it, and on the fact that its tissues live for a long time after the brain is destroyed and sensibility lost, and after the animal as a whole is dead.

Cut off the head of a frog as low down as possible with a sharp pair of scissors. It is thus made quite incapable of feeling or movement. Cut a hole half an inch across in a thin piece of wood, and pin out the web between two of the toes of the frog over the hole (it will be better if a ring of cork is glued round the hole to put the pins into), and examine the most transparent part of the web with the low power of the microscope.

We have seen in the dissection of the rabbit the large artery, the aorta, which carries the blood from the heart to the organs and the large veins, the superior vena cava and the inferior vena cava, which carry it back to the heart again. The aorta gives off branches to the several parts of the body, and these branches divide again into other branches, and so the branching can be traced on to a large number of small arteries in the various organs. In a similar way, the large veins can be seen to be made up by the union of a large number of small veins coming from the various organs. The blood passes from the small arteries to the small veins of an organ in very minute tubes — the **capillaries**. Capillaries, with the blood passing along in them, can be seen easily in the web of the frog's foot. The web consists of thin skin on each side, with a little connective tissue between the two layers of skin. In this tissue blood-vessels lie. If the web is held up to the light, small vessels will be seen as fine red lines branching away from the larger vessels running along at the side of each toe; with the microscope, a network of branching vessels will be seen throughout the web. The finest of these are the capillaries, the larger are the small arteries bringing the blood from the heart, and the small veins carrying it back to the heart.

Blood-vessels are in all cases not mere spaces in the tissue, but tubes having walls of their own. The walls of the capillaries are, however, very thin, and in them the corpuscles of the blood can be seen as they are carried along. In some places the current will be too swift for the corpuscles to be seen distinctly. The red corpuscles of the frog are, as we have said,

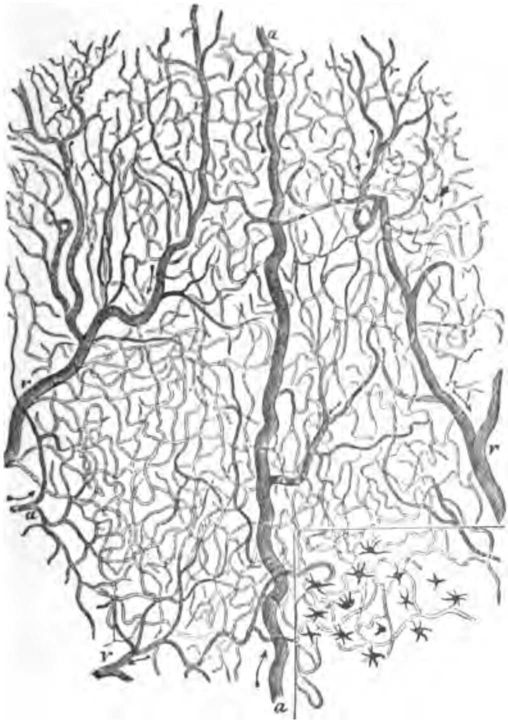


FIG. 8. — Blood-vessels of the web of a frog's foot seen by a low magnifying power.

a, small arteries; *v*, small veins. The minute tubes joining the arteries to the veins are the capillaries. The arrows show the direction of the circulation. In the small portion marked off, the pigment cells, which occur throughout the web, are also represented.

oval in shape, and are about three times as large as those of man. In the small arteries, veins, and larger capillaries they are seen going along two, three, or more abreast; in the smaller

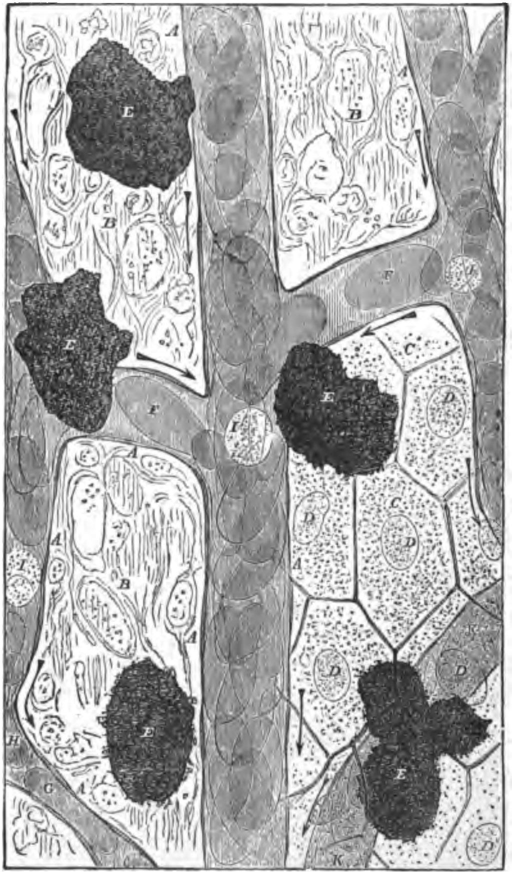


FIG. 9.—Capillaries of the web of a frog's foot very highly magnified.

A, wall of capillaries; *B*, tissue of the web in which the capillaries lie; *C*, large many-sided cells of the thin skin covering the web; *D*, nuclei of these cells; *E*, cells containing black pigment; *F*, red corpuscles; *G*, *H*, red corpuscle being squeezed through a narrow capillary; *K*, a capillary seen through the thin skin; *I*, colourless corpuscles.

capillaries they follow each other in single file. When they pass into a small branch they bend and change their shape, and some may be seen flattened and elongated as they are being squeezed through the smallest capillaries; directly they get room, they recover their proper shape again. Colourless corpuscles, which are smaller than the red corpuscles, being about the same size as the colourless corpuscles of man, will also be seen. In the small arteries the red corpuscles will be carried swiftly along in the centre or axis of the vessel, while the colourless corpuscles, being lighter and more adhesive, will be carried along more slowly at the side of the stream. The colourless corpuscles are often seen, especially in the capillaries and small veins, to stick to the wall of the vessel for a time and then to be carried on again.

The oxygen and nourishment which the tissues require is constantly passing from the blood through the walls of the capillaries, and similarly the waste matters which the tissues form pass through the walls into the blood.

Before we consider the course the blood takes in its circulation, or the means by which its circulation is carried on, it will be well to consider the build and movements of the body, and the nature of some of the tissues.

CHAPTER V

THE SKELETON

FREE the bones of a rabbit as much as possible from flesh, but without separating more than necessary the bones from one another, bury them or allow them to soak in water for two to three weeks. Or the bones of a rabbit, after boiling, may be treated in the same way. Then wash them well and expose them to the sun to dry. Prepare in this way the skull, several vertebræ and ribs, the shoulder and hip bones, and the larger bones of the limbs. Compare the bones and joints with the description given below of the bones and joints of man.

The skeleton consists of: —

1. The bones of the trunk and neck, namely, the vertebral column, ribs, sternum, and the pectoral and pelvic girdles.
2. The bones of the head, namely, the cranium and the bones of the face.
3. The bones of the arms.
4. The bones of the legs.

The Vertebral Column. — The vertebral or spinal column is the bony axis of the body. It consists of distinct bones, called vertebræ, placed one upon another. The vertebral column is divided into regions as follows: —

1. The cervical region, or region of the neck, consisting of seven vertebræ.
2. The dorsal region, or region of the back, consisting of twelve vertebræ.
3. The lumbar region, or region of the loins, consisting of five vertebræ.
4. The sacral region, consisting of five vertebræ united together to form a single bone, the sacrum.

5. The coccygeal region, consisting of four imperfect vertebræ often united together into one bone called the coccyx.

The **vertebræ** are alike in general form. One of the dorsal vertebræ may be taken as the type. It consists of a nearly circular solid mass of bone, about one and a half inch across, and nearly an inch thick, called the **body**. The body bears, on the dorsal side, a ring or arch, the **neural arch**, and from this arch **three processes** project out, one projecting backwards, in the middle, opposite the body, the spinous process; and one on each side, the transverse processes. The bodies of the vertebræ are separated from one another by pads of what is called fibrous cartilage about one-fourth of an inch thick placed between them. These are the **intervertebral discs**. Each disc is

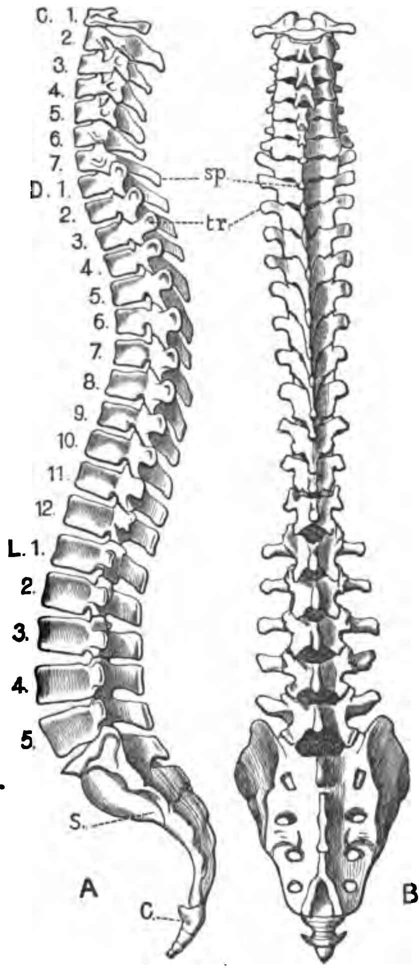


FIG. 10. — The vertebral column.
A, side view, left side; B, back view; C 1–7, cervical vertebræ; D 1–12, dorsal vertebræ; L 1–5, lumbar vertebræ; S, sacrum; C, coccyx; sp, spinous processes; tr, transverse processes.

firmly attached to the body of the vertebra on each side of it, so that it serves not only as a cushion between them, but binds them together. The arch of one vertebra touches the arch of the next above and below at a smooth prominence on each side, and the two are united together by ligaments at these spots, forming a double row of joints. There are also ligaments passing from vertebra to vertebra down the front and back of the bodies of the vertebræ, as well as ligaments connecting the arches and processes of one vertebra to the next, so that these are strongly bound together into a firm but slightly flexible column.

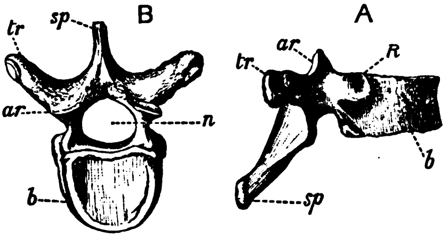


FIG. 11. — A dorsal vertebra.

A, side view, right side; B, view from above; *b*, body; *tr*, transverse processes; *sp*, spinous process; *ar*, place on the arch for articulation with vertebra above; *R*, place on body for articulation of end of rib; *n*, canal for spinal cord.

Since the arches of the vertebræ lie over one another, they form together a canal, and in this the spinal cord lies, so that not only do the bodies of the vertebræ united together form a support for the trunk, but also the arches form a protection for the spinal cord. The spinal column is not straight; it is arched forwards in the cervical region, backwards in the dorsal region, forwards again in the lumbar region, and, lastly, backwards in the sacral region. These curves give grace and elasticity to the trunk, and allow the back to be bent to a certain extent forwards and backwards. The spinal column has also a little play from side to side, and will even allow a very little twisting movement at the joints between the vertebræ.

The first cervical vertebra is called the **atlas**, and differs in form from the other vertebræ. It is ring-shaped, and without any proper body, only the anterior part of the ring corresponding in position to the body of a typical vertebra. The second cervical vertebra, called the **axis**, is also peculiar, for its body carries a process which goes into the front part of the ring of the atlas. This process, which is called the **odontoid process**, has a smooth part where it meets the inner side of the front part of the ring of the atlas, and so has the ring itself, so that the atlas can move round for a considerable way on the axis, with the odontoid process as a pivot. The odontoid process is kept in place by a ligament lying just behind it, across the ring of the atlas, and this separates the process from the spinal cord, which passes through the ring. The lower surface of the atlas has also two surfaces by which it forms joints with the axis, as do the other vertebræ to one another; it is the looseness of these joints which allows the atlas to turn on the axis as far as it does. The upper surface of the atlas has two smooth surfaces on which the skull rests. These are joints which allow a backward and forward movement of the skull; when the head is moved backwards and forwards as in nodding, it moves on the atlas, which is kept fixed. When the head is moved round, the atlas is moved with it, the latter turning on the axis with the odontoid process of the axis as the pivot. There are two ligaments, the check ligaments, passing from the top of the odontoid process to the skull, which limit the amount of rotation. When the head is tilted to one side, the cervical region of the spinal column is bent, the cervical vertebræ allowing a considerable amount of play from side to side.

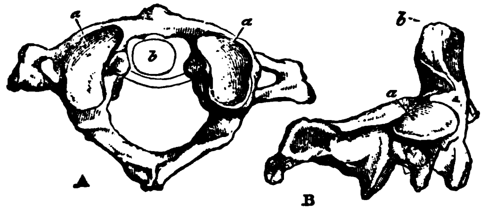


FIG. 12. — The atlas and axis.

A, the atlas from above; *a*, areas for articulation with skull; *b*, odontoid peg of axis, with ligament behind it.
B, side view of axis vertebra, right side; *a*, areas for articulation with atlas; *b*, odontoid process or peg.

The **sacrum** is a wedge-shaped bone with the broad end above and the narrow end below. The upper end articulates with the last lumbar vertebra by a joint on each side, and is connected to it in the centre by an intervertebral disc as well as by ligaments. The lower end carries the coccyx. The sacrum is formed in the infant as five vertebræ, but these in adult life unite to form one bone. Since the arches of the vertebræ unite as well as the bodies and the processes, they form by their union a canal running down the back of the bone in which lie the nerves coming out from the end of the spinal cord; the cord itself ends at the level of the second lumbar vertebra.

The **coccyx** consists of a row of four small bones, the upper-

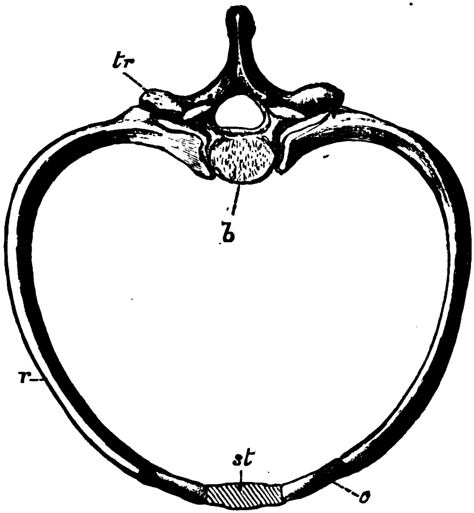


FIG. 13.—Articulation of a pair of ribs to a vertebra.
b, body of the vertebra; *tr*, transverse process; *r*, rib; *c*, costal cartilage; *st*, sternum.

most one being united by a joint to the sacrum. In adult life these four bones are usually united into one. They are the rudiment of the many vertebræ of the tail in other animals.

The Ribs and Sternum.—The ribs are twelve in number on each side. Each rib is attached to the corresponding dorsal vertebra, so that each dorsal vertebra carries a pair of ribs. Each rib is articulated to the vertebra at two places, at the transverse process of the vertebra, and on the body of the vertebra. In the case of most of them also each rib just touches the body of the vertebra above that to which it belongs. These joints allow movement up and down. As the ribs leave the vertebral column and sweep round to form the wall of the thorax, they slope a little downwards. The first ten ribs are connected to the sternum. The last portion of each rib, just before it meets the sternum, consists of cartilage, not bone. These are called the **costal cartilages**. The first seven ribs join the sternum separately, but the cartilages of the next three are connected first to each other, and then to that of the seventh rib; so that they join the sternum indirectly only. The last two ribs, the eleventh and twelfth, are short and do not reach the sternum. They are called floating ribs (see Fig. 4, page 23).

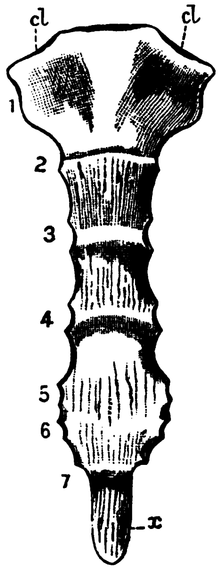


FIG. 14.—Sternum viewed from in front.

1, 2, . . . 7, places of attachment of the first seven ribs; *cl*, places of attachment of clavicles; *x*, lower projecting end of sternum.

The **sternum** is a flat bone rather more than six inches long, and two and a half inches broad above, but narrow below. It is something like a dagger in shape. The cartilages of the first seven ribs meet it on each side, but it projects a considerable way beyond the place where the seventh rib meets it. The collar bone on each side is attached to it above.

The Pelvic Girdle.—The pelvic girdle, to which the thigh bones articulate, is a strong arch springing from the sacrum. It is formed by a large irregular bone, the hip bone, on each side, which arches round the lower part of the abdomen, and meets its fellow in the middle line in front. Each hip bone is firmly attached to the side of the sacrum, so that the sacrum is wedged in between the two hip bones, like the keystone of an arch. Each hip bone has a large flat surface, which forms part of the wall of the lower part of the abdomen at the sides, and gives attachment to the large muscles of the buttock.

The pelvic girdle, thus arching round, makes the lower end of the abdomen basin-shaped, and the cavity so formed is called the pelvic cavity, and the bony walls of the cavity the **pelvis**.

The Pectoral Girdle. — The pectoral girdle is an imperfect arch to which the arm bone is articulated. It consists of two bones, the collar bone, or **clavicle**, and the shoulder bone,

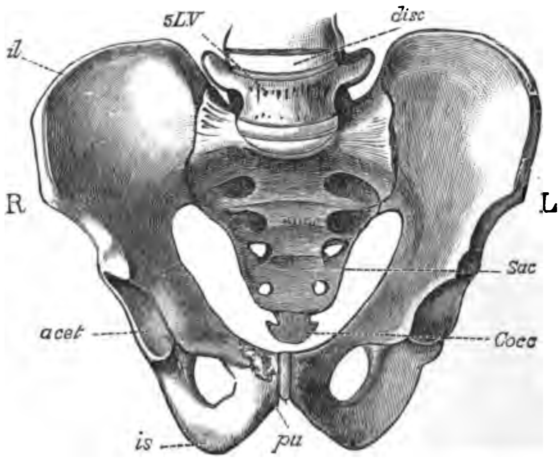


FIG. 15. — The pelvis.

Sac, sacrum; *Cocc*, coccyx; *il*, *is*, *pu*, ilium, ischium, pubes, three parts of the innominate or hip bone; *acet*, acetabulum, cup for head of femur; *5 L. V*, 5th lumbar vertebra.

or **scapula**. The clavicle is a long narrow bone, about six inches long, passing from the sternum outwards to a prominence of the scapula projecting over the shoulder joint. The scapula is placed behind, and is a large, flat triangular bone, with a prominent ridge extending across it at the back outwards to the shoulder. It gives attachment to the large muscles passing to the back of the arm. It articulates with the clavicle at the shoulder and supports the arm, but is otherwise free, not connected to the vertebral column, so that it is very movable.

Bones of the Limbs

The skeleton of the arm and that of the leg are arranged on the same plan, namely, with long and narrow bones, called "long" bones, in each segment of the limb, small irregular bones at the wrist and in the foot, and small "long" bones in the fingers and toes.

Arm. — **Humerus.**	Thigh. — **Femur.** (Knee-cap — **Patella.**)
Forearm. — **Radius** and **ulna.**	Leg. — **Tibia** and **fibula.**
Wrist. — **8 carpal bones.**	Ankle and heel. } **7 tarsal bones.**
Hand. — **5 metacarpal bones.**	Foot. — **5 metatarsal bones.**
Fingers. — **Phalanges** — **3 in each finger, 2 in thumb.**	Toes. — **Phalanges** — **3 in each toe (except big toe which has 2 only).**

The long bones consist of an upper end or head, a shaft, and a lower end. The ends are variously shaped according to the kind of joint into which they fit. These will be best described with the joints.

Bones of the Head

All the bones of the skull, except that of the lower jaw, are united firmly together by the interlocking of their toothed edges with one another. The skull consists of the cranium or brain case and the bones of the face.

The Cranium. — The cranium consists of irregular bones at the base, and of flat bones arching up forming the sides, roof, back, and front. There are six of these flat bones; namely, two **temporal** at the temples, two **parietal** at the sides, passing up to meet each other in the middle of the roof, the **frontal** in front, and the **occipital** behind. The occipital bone forms also part of the base of the skull and has a large hole through which the spinal cord becomes continuous with the brain. On each side of this hole is a smooth surface by which the bone articulates with

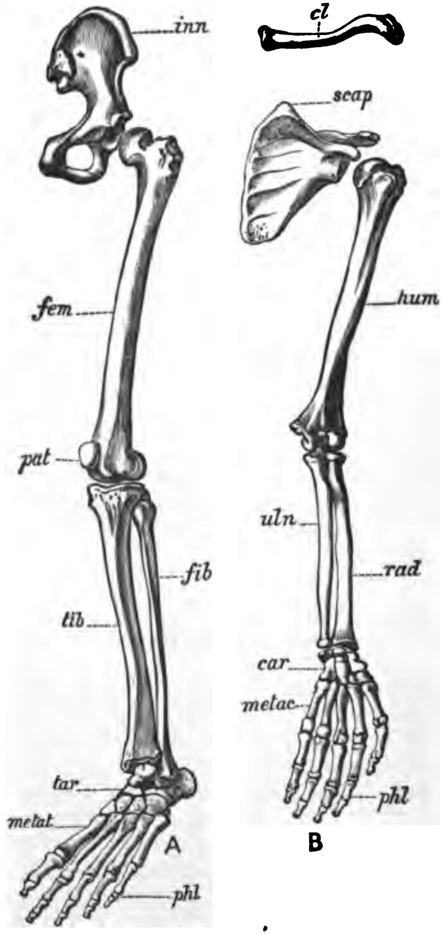


FIG. 16. — The bones of the limbs. Front view. Left limbs.

A, the innominate and bones of the leg; B, the scapula, clavicle, and bones of the arm.

the atlas, and by these surfaces the skull rests on the vertebral column. The rest of the base of the cranium in front of the occipital bone is formed chiefly by a very irregularly-shaped bone called the **sphenoid**, and by a part, the petrous part, of the temporal bones.

Bones of the Face. — The bones of the face consist of the bones of the upper and lower jaws, the nose, cheeks, and palate. The **orbits** or sockets for the eyes are formed by the upper jaw

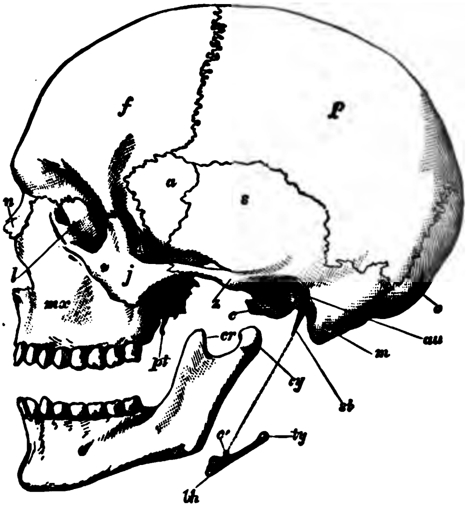


FIG. 17. — Side view of the skull.

f, frontal bone; *p*, parietal; *o*, occipital; *a*, wing of sphenoid; *s*, flat part of temporal; *c*, *m*, *st*, other parts of temporal; *au*, opening of ear or external auditory canal; *z*, process of temporal passing to *j*, the cheek bone; *mx*, the upper jaw bone; *n*, nasal bone; *l*, lacrymal; *pt*, part of sphenoid. The lower jaw bone is drawn downwards; *cy*, its process which articulates with the temporal; *cr*, its process to which muscles of mastication are attached; *th*, *ty*, hyoid bone.

bone below, by the frontal bone above, and the cheek bones at the outer side with a small bone, the **lacrymal**, in each orbit. The lower jaw bone is the strongest and thickest bone of the face. It is shaped like an arch, with the bend of the arch forward forming the chin, and with two flat side pieces passing backwards and upwards to the joint which it forms with the temporal bone on each side just below the ear. The joint acts mainly as a hinge joint, which allows a good deal of side to side movement and some backward and forward movement as well as up and down movement.

In adult life there are about 206 distinct bones in the body, of which twenty-two are in the skull, but the number varies a little according to age, because some of the bones unite with other bones as life advances.

CHAPTER VI

JOINTS

EXAMINE carefully the joints of a rabbit. The most important joints to study are the shoulder and hip joints, and the elbow and knee joints. The structure is essentially the same in these animals as in man. The bones of the fore-quarter of a lamb may be conveniently examined for the shoulder joint.

Immovable Joints. — Unions of bones, where no movement is allowed, are formed by the interlocking of the bones of the skull with one another.

Movable Joints. — Movable joints are classified according to the kind of movement they allow.

1. Gliding joint, allowing a small amount of movement. Example — the joints between the vertebræ.
2. Hinge joint, allowing backward and forward movement like a hinge. Examples — elbow, knee, ankle.
3. Ball and socket joint, allowing movement in all directions, and also rotation. Examples — hip, shoulder.
4. Pivot joint, allowing movement of rotation only. Examples — the atlas on the axis, the radius on the ulna.

The ends of the bones which meet in a joint are bound together by ligaments of fibrous tissue, usually in the form of strong bands, but one of the ligaments is thin and forms a bag round the ends of the bones. This bag is quite closed by being attached all round the bones a little distance from their ends. It is called the **capsule** of the joint. The ends of the bones which meet inside the capsule are tipped with a thin layer of cartilage, and this is covered with a smooth transparent membrane, as is also the inside of the bag itself. This membrane is called the **synovial membrane**; it is moist with a fluid, the synovial fluid, which facilitates the movements.

Let us examine a few joints in detail.

The Shoulder Joint.—The upper end of the humerus is rounded into a smooth head, fitting into a shallow cup-like depression in the scapula, forming a ball and socket joint. The capsular ligament forms a loose bag, attached all round the cup of the scapula, and all round the humerus just below the head. Band-like ligaments also connect the humerus with the scapula. The synovial cavity, the cavity enclosed by the capsule, is large and the joint very free, so that the arm can be moved in all directions and rotated. When the arm is raised to the horizontal position, the humerus is brought up to the parts of the scapula projecting over the shoulder joint, and so the upward movement between the humerus and the scapula is limited. When the arm is raised beyond this the scapula is moved with the arm.

The Hip Joint.—The upper end of the femur is round, forming a large ball-like head, connected by a neck to the shaft; this fits into a deep cup-like socket in the hip bone. The capsular ligament is attached round the edge of the cup and round the femur just beyond the head. It is much thicker in front than behind, the front forming, in fact, a strong band-like ligament across the front of the joint. There is also a round cord-like ligament, the round ligament as it is called, passing from the head to the bottom of the cup, inside the joint. The round ligament is sufficiently long to allow the femur a good deal of play. The hip joint, like other ball and socket joints, allows movement in all directions, but the range is not so extensive as at the shoulder joint, because the socket is deeper and the capsule forms a closer bag. Moreover, the hip bone cannot move in the same way as the scapula can.

The Knee Joint.—The knee joint is a hinge joint between the femur and the tibia; the fibula has no share in it. The upper end of the tibia is broad, and has on its upper surface two shallow depressions side by side, the articular surfaces. hese are deepened by a band of fibro-cartilage, semilunar in shape, running round the outer edge of each. The lower end of the femur is enlarged by two bosses, each having a large rounded articular surface. These articular surfaces are extensive and meet each other in front, and then continue a little distance up the front of the bone. Only a small part of each articular surface of the femur is in contact at any one time with the

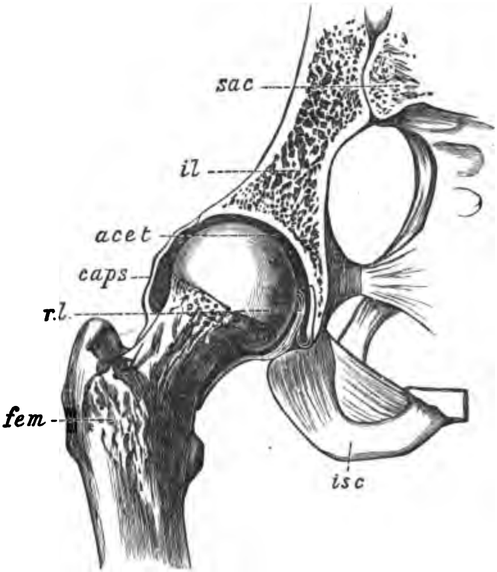


FIG. 18.—The right hip joint. The hip bone sawn through so as to show the cup of the joint.

fem, femur; *il*, ilium; *isc*, ischium; *sac*, sacrum; *acet*, cup or acetabu'um; *caps*, capsule; *r.l*, round ligament.

articular surfaces of the tibia. When the knee is bent the hind part of these surfaces are in contact with the tibia, and when the knee is straightened the front part.

There are two ligaments like the round ligament in the hip joint, in the middle of the knee joint, passing from the tibia to the femur. These, called the crucial ligaments, cross each other from side to side. The capsular ligament enclosing the joint is strengthened in front by the presence of a triangular bone, the knee cap, or **patella**. The inner surface of the patella is polished and covered by synovial membrane like the rest of the interior of the joint; it plays on the large articular surface on the front of the femur when the knee is bent and straightened. The patella lies, as it were, in the capsular ligament, but is attached to the tibia by a strong band-like ligament as well. To the upper edge of the patella the tendon of the muscle which straightens the leg, the extensor muscle as it is called, is attached, so that by means of the patella and the band-like ligament below it, this muscle is attached to the tibia.

FIG. 19. — The right knee joint. The outer half of the femur and patella sawn away.

fem, femur; *pat*, patella; *tib*, tibia; *fib*, fibula; *caps*, capsule of joint; *l*, crucial ligaments; *c*, semilunar fibro-cartilages; *e*, tendon of extensor muscle.

There are other band-like ligaments at the sides and at the back of the knee joint which help to keep the bones in place, and, with the crucial ligaments, prevent the leg being bent forwards at the knee.

The fibula, the smaller bone of the leg, lying alongside the tibia, on the outer side of the leg, does not reach quite as high as the knee joint, its upper end being articulated with the tibia just below. The lower ends of the tibia and fibula form the inner and outer prominences at the ankle, and are articulated with the bones of the foot.

The Elbow Joint. — The elbow joint is a hinge joint between the humerus above and the ulna and radius below. The lower end of the humerus is broad from side to side and presents a rounded edge. This smooth edge is divided into two parts by a ridge. The ulna articulates with the part on the inner side of this ridge, and the radius with the part on the outer side. The upper end of the ulna forms the bony prominence at the elbow. Just below this, on the front of the ulna, is a large, deep, smooth notch. Into this notch the inner half of the rounded lower edge of the humerus fits. The upper end of the radius has a round disc-like head attached by a neck to the shaft. The top of the head is smooth and concave, and into this the outer half of the articular surface of the humerus fits. Movement at the elbow joint consists of flexion and extension only, the ulna and radius both gliding on the rounded lower edge of the humerus. The joint is enclosed by capsular and band-like ligaments, the strongest of which is in front of the joint, and this prevents the arm being bent backwards at the elbow joint. The forearm cannot be bent quite down on the arm because the fleshy parts of the two come together.

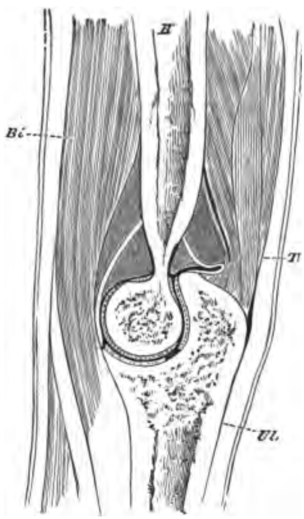


FIG. 20. — The elbow joint — Longitudinal section.

H, humerus; *Ul*, ulna; *Tr*, the triceps muscle behind straightens the arm; *Bi*, the biceps muscle in front bends the arm. The white line round the joint, in this position thrown into a fold behind the joint, represents the capsular ligament.

Pronation and Supination of the Forearm. — The ulna is capable of no other movement than flexion and extension at the elbow joint, but the radius can also turn on the ulna. The edge of the disc-like head of the radius is smooth, and touches a concave smooth surface on the outer side of the ulna, the head being held in place by a ring-like ligament going round it. The lower end of the radius is broad, and it alone articulates with the carpal bones at the wrist, and thereby carries the hand, the ulna not entering into the wrist joint. On the inner side of the lower end of the radius there is a shallow depression into which fits the small rounded lower end of the ulna. When the palm of the hand is forwards or looks upwards, the two bones of the forearm lie parallel to each other, the radius on the outer side of the ulna. This is the position of **supination**. When the hand is turned so as to bring the thumb inwards and the back of the hand forwards or looking upwards, the radius rotates lengthwise, and its lower end moves across the front to the other side of the lower end of the ulna, describing a complete half-circle. In this position, which is called that of **pronation**, the radius lies obliquely across the front of the ulna from the outer side at the elbow to the inner side at the wrist. In the movement of pronation, the upper end of the radius does not move its position, but merely turns on its axis, the cup at the end of the head turning on the humerus, and the edge of the head gliding on the side of the ulna; while the lower end of the radius, as the bone rotates, travels round the lower end of the ulna, which remains fixed at its pivot. The lower articulation, then, between the radius and the ulna is a pivot joint, the ulna being the pivot, and the upper articulation is a peculiar pivot joint, the radius rotating on itself, the axis of the bone being the imaginary pivot.

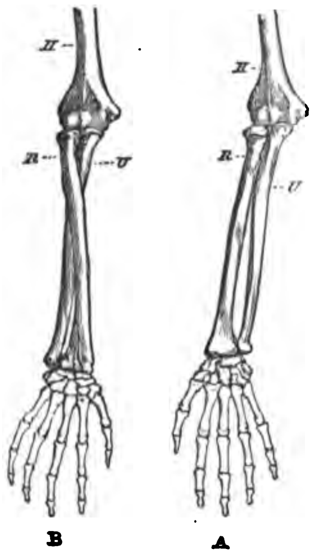


FIG. 21.—The bones of the right forearm in supination and pronation.

A, supination; B, pronation; *H*, humerus; *R*, radius; *U*, ulna.

Joints of the Wrist and Hand.—The movements at the wrist joint take place between the radius and the first row of carpal bones, between the carpal bones themselves, and between the second row of carpal bones and the metacarpal bones. Numerous ligaments keep the bones in place. The wrist chiefly acts as a double-hinge joint, allowing the hand to be bent backwards and forwards, and also allowing a movement inwards towards the ulna and slightly outwards towards the radius. The joints between the fingers and the hand, that is, between the first phalanges and the metacarpal bones of the hand, are ball and socket joints. The two joints of the fingers are hinge joints.

CHAPTER VII

STRUCTURE OF THE SUPPORTING TISSUES — CARTILAGE, CONNECTIVE TISSUE, AND BONE

OBTAIN specimens of cartilage from the sternal ends of the ribs of a rabbit, a sheep (or, better still, a lamb), or from the larynx. Cut the thinnest possible slices or sections, as such slices are called, from a piece of cartilage with a razor. Put a very small and thin fragment on a glass slide, add a drop or two of water, and cover it with a thin glass cover slip, taking care that no water gets on the outer side of the cover slip. Examine the thinnest edge with a microscope.

Cartilage. — Cartilage (gristle) is tough but flexible, so that it can be bent by pressure though only slightly; it is also elastic, that is, it returns to its original form when the pressure is removed. In thin pieces it is semi-transparent and white or bluish-white in colour. When a piece is obtained fresh from the animal it is seen to be covered by a thin fibrous membrane which is reddish because it contains blood-vessels, that is, the fibrous membrane is vascular. This membrane can be readily stripped off, and then the cartilage it covers shows no sign of redness, that is, contains no blood-vessels, is **not vascular**. To the naked eye it appears to be uniformly of the same substance throughout, but examination with the microscope shows that scattered in the general substance are numerous **cells**. Each cell is oval or rounded in shape, and contains a round nucleus. The cell, just as a colourless corpuscle does, consists of cell substance, which is largely living material, containing embedded in it, besides the nucleus, numerous minute granules, some of which are often globules of fat. The solid substance of the cartilage in which the cells lie, the **matrix** as it is called, shows no structure, but is a little different in nature close round each cell from what it is farther off. The living cells continue to live for some time after the cartilage is taken from the animal, but when they die often shrink away from the matrix, so that it is clearly seen that they lie in cavities in the solid matrix. The cells are often in pairs, and in that case each is somewhat triangular or half-moon shaped; this at once suggests that they have been formed by the division of one cell. This is actually the case. In the growth of the cartilage each cell divides into two cells, and the two new cells as they grow themselves, become more and more separated from each other by the formation of matrix between them. These new cells will later on divide in a similar way, so that a group of four, eight, or more cells which have all sprung from one cell may be seen.

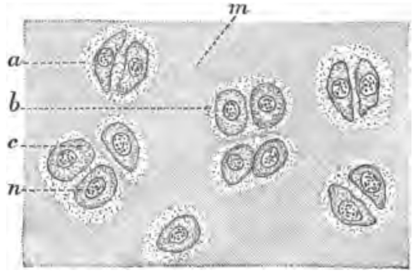


FIG. 22. — Hyaline cartilage. A thin section highly magnified.

m, matrix; *a*, group of two cartilage cells; *b*, a group of four cells; *c*, a cell; *n*, nucleus.

Varieties of Cartilage. — The matrix instead of being clear and semi-transparent, hyaline as it is called, is sometimes fibrous, and of this there are two varieties. So that there are three kinds of cartilage: —

1. **Hyaline cartilage.**
2. **Fibro-cartilage.** — In the matrix are masses of fine wavy parallel fibres.
3. **Elastic cartilage.** — In the matrix is a close network of branched fibres, which make the cartilage especially elastic. It is yellow in colour.

Cartilage occurs in the following parts of the body of an adult: —

Hyaline cartilage.

(1) Forming a thin layer at the ends of the bones where they meet at all movable joints.

(2) The costal cartilages connecting the ribs to the sternum.

(3) Parts of the larynx.

(4) In the trachea.

Fibro-cartilage.

(1) The inter-vertebral discs.

(2) The inter-articular cartilages, such as the semilunar cartilages in the knee joint and those which form a ring round the edge of the cup, in the hip, shoulder, and other joints, and so deepen the socket.

Elastic cartilage.

(1) In the ear.

(2) Parts of the larynx.

In the young child there is much more cartilage than in the adult, for all the bones in the body, except some of those of the cranium, are formed of cartilage first, which is gradually changed to bone.

Purposes fulfilled by Cartilage. — The formation in early life, of what will become the bones of the body, is a most important purpose fulfilled by cartilage. It supplies throughout life the smooth caps to the ends of bones within joints. It furnishes also firm but elastic connections between bones, as between the ribs and the sternum, and between the vertebræ. It is of service also in forming firm but slightly yielding walls for such an organ as the larynx, and for keeping open the trachea, or of giving firmness and yet elasticity to projecting structures, such as the epiglottis and the ears. It is also of use in deepening the sockets of joints.

Connective Tissue

Connective tissue is the tissue, varying in the closeness of its texture, which is found throughout the body, lying between and connecting different organs or different parts of an organ with one another; hence its name.

Connective tissue, such as that just under the skin, consists of a close meshwork formed of bundles of fibres, white in colour, running in various directions. The bundles consist of extremely fine long wavy fibres, or **fibrillæ**, as they are called. The fibrillæ run parallel in the bundles and never branch. Bundles of such fibrillæ do not stretch, are not elastic. If very dilute acid is allowed to act on the fibrillæ they swell up and become almost transparent. Scattered among these bundles of fine fibrillæ are some branching fibres, generally much thicker, which form a loose network; these are elastic, and are called **elastic fibres**. They are yellowish in colour.

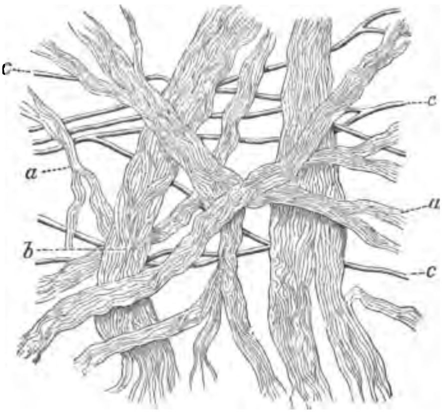


FIG. 23. — Connective tissue fibres.
a, small bundles of white fibrous tissue; *b*, larger bundles; *c*, single elastic fibres.

Lying among the bundles of fibres are a number of cells, called **connective tissue corpuscles**. Each contains a nucleus. Many of them are flattened and much branched, and lie on the surface of the bundles of fibrillæ. Others lying in the meshes formed by the fibres are more like the colourless corpuscles of the blood. The three elements of connective tissue then are, fine fibrillæ, elastic fibres, and connective tissue corpuscles.

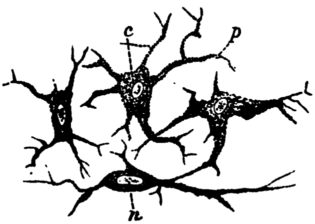


FIG. 24. — Connective tissue corpuscles.
c, cell; *p*, process; *n*, nucleus.

The connective tissue between the muscles is much looser in texture than that immediately under the skin, but consists of the same three elements. Tendons and ligaments, on the other hand, are formed of very dense connective tissue.

Tendons, connecting muscles to bones, consist of strong bundles of white connective tissue fibres closely packed together. Flattened branched cells lie between the bundles of fibres.

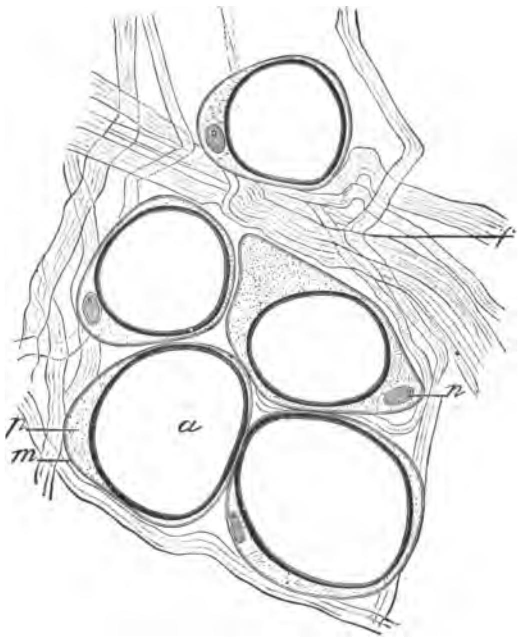


FIG. 25. — Adipose tissue.

a, globule of fat lying in a cell; *m*, the membrane or layer of cell substance, *p*, covering the globule; *n*, nucleus; *f*, bundles of connective tissue fibrillæ. Five fat cells are seen.

Ligaments, connecting bones to bones, consist also of fibrous connective tissue, but contain in addition a large number of elastic fibres. Some ligaments consist almost entirely of elastic fibres, and are yellow in colour. This is especially the case with some ligaments of the spine, and particularly so in grazing animals.

When connective tissue, tendons, or ligaments are boiled, the material forming the white fibrillæ is converted into **gelatin**, a substance somewhat like a proteid, solutions of which have the property of setting into a jelly when cold. All animal jellies are obtained from some form of connective tissue.

Fatty Tissue. — Connective tissue often contains much fat. Such tissue is called fatty tissue or adipose tissue. The fat exists in fat cells which are really large modified connective tissue cells. The fat is first deposited in the form of minute globules in the cell substance of the connective tissue cell, and these minute globules gradually increase in size and run together, forming a single globule of fat which remains covered by a thin layer of the cell substance of the cell.

Fatty tissue occurs chiefly just under the skin, and in other places filling up inequalities. It gives roundness to the limbs. Its important service is to act as a store of nutriment for the body.

Bone

Clear one or two long bones, femur or humerus, of a rabbit, sheep, or pig, free from muscles and tendons, and examine them either at once or after treating them as directed below.

A Fresh Bone. — A bone such as a long bone is covered, except at the ends tipped with cartilage and lying within the joints, by a vascular membrane, the **periosteum**. The periosteum consists of fibrous connective tissue, rich in blood-vessels. The periosteum, which is closely adherent to the bone, may be removed by scraping, and the bone itself is then seen to be reddish in colour; it also is **vascular**. On the surface, especially near the ends, there are numerous minute holes, by means of which small blood-vessels from the periosteum pass into the bone. Near the middle of the shaft is an aperture, the hole through which the main artery and vein pass to and from the inside of the bone from and to the large artery and vein running in the limb.

If the bone be sawn across the middle of the shaft it will be

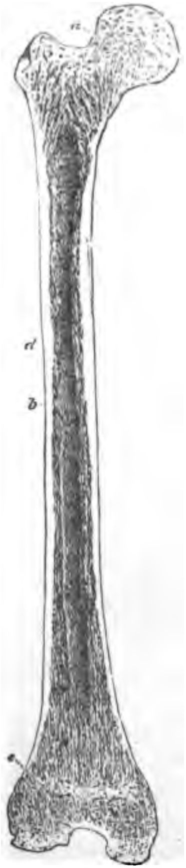


FIG. 26. — The femur cut lengthwise.

a, the upper end consisting of spongy bone; *b*, the marrow cavity; *c*, the spongy bone of the lower end; *d*, the compact bone of the shaft, left unshaded in the figure.

seen to be hollow, the bone enclosing a cavity, the **medullary cavity**. This cavity contains the **marrow** or medulla, a vascular and therefore reddish tissue containing much fat.

If the bone be sawn longitudinally, the medullary cavity will be found to extend along the whole length of the shaft and down to the enlarged ends, but not into the enlargements. The bone at the ends is not dense or compact as in the shaft, but spongy or, as it is called, cancellous. The marrow of the medullary cavity with the blood-vessels in it extends into the cavities of the spongy bone, and numerous blood-vessels pass from the medulla into the compact bone along the length of the shaft also. The bone is thus well supplied with blood-vessels, partly from the periosteum and partly from the marrow. In the spongy bone the vessels lie in the marrow in the cavities of the sponge work; in the compact bone they lie in numerous canals running longitudinally along the shaft. These canals, called the **Haversian canals**, which, although they run mostly longitudinally, are connected with one another, open here and there inwards into the medullary cavity and outwards on to the surface of the bone, and at these openings blood-vessels enter them from the medulla or from the periosteum. Some bones have no medullary cavity, being merely cancellous or spongy within; such are the ribs, vertebræ, and some of the smaller bones. Although the enlargements at the ends of a long bone are loose or spongy in texture they are really as strong as the shaft, for the various sheets and spicules of bone making up the sponge work run in such a way as best to bear the pressure or strains to which the bone is liable.

A Dry Bone.—A bone which has been macerated or buried for a few weeks and then exposed to the air, is called a dry bone, and may be preserved indefinitely. All the soft parts have decayed away, the periosteum, the marrow, and the contents of the cancelli and of the Haversian canals have disappeared, and the bone has become yellowish-white in colour. If a slice of the compact bone cut transversely to the shaft be ground down till it is very thin it can be examined microscopically. The Haversian canals being cut across appear as holes, and around these are concentric lines showing that the bone is laid down in layers or **lamellæ** round the canals. Examined more closely, the concentric lines are seen to be formed by a number of irregular spaces connected together arranged in circles round each Haversian canal. These spaces are called **lacunæ**, and from them numerous minute wavy canals pass inwards to open into the Haversian canal, while others pass outwards to open into the lacunæ in the outer circles or lamellæ.

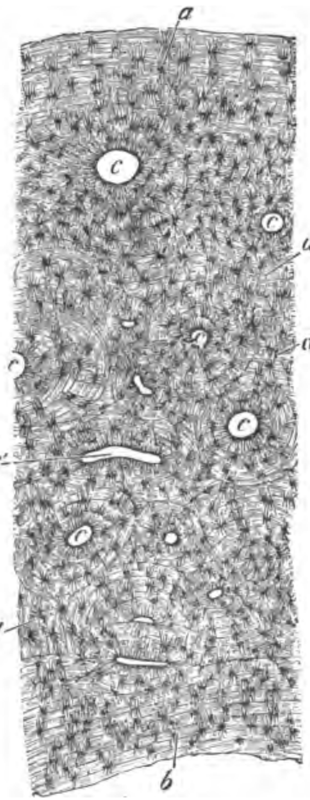


FIG. 27.—Compact bone—transverse section. Magnified.

a, lamellæ of bone parallel or concentric with the external surface; *b*, lamellæ concentric with the surface next the marrow; *c*, Haversian canals cut across with lamellæ arranged round them; *c'*, a canal just dividing into two; *d*, lamellæ between the Haversian systems.

These minute canals or **canaliculi**, as they are called, supply channels by which nutrient fluid exuding from the blood-vessels in the Haversian canal can pass from the Haversian canal to the bone immediately around to nourish it, the bone being made up in this way of a number of **Haversian systems**.

A Decalcified Bone. — A bone is hard, owing to the presence in it of mineral matter. If a bone is allowed to soak

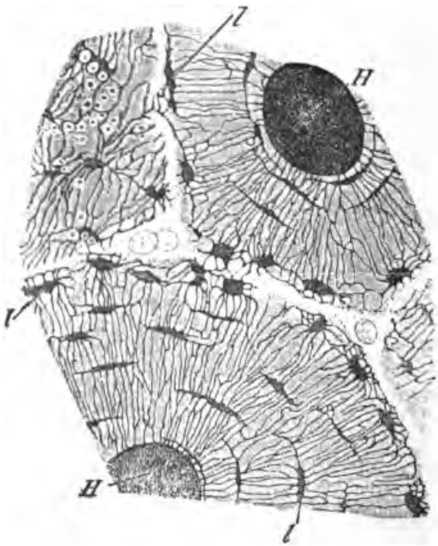


FIG. 28. — Transverse section of bone. Highly magnified.
H, Haversian canals; *l*, lacunæ with canaliculi.

in acid for a few days it loses its hardness and becomes soft and flexible, although it retains its original shape. Such a bone has had the earthy salts dissolved out of it, and is said to be decalcified. If a fresh bone be treated in this way and then a thin section of it be examined, the Haversian systems will be seen as before, and in each lacuna will be a small cell, a **bone corpuscle**, as it is called, containing a nucleus, and the cell substance having fine processes going for some distance along the canaliculi. In fact, the bone corpuscles lie in the bone matrix in much the same way as cartilage cells lie in the cartilage matrix.

A Burnt Bone.—If a bone is heated in a red fire the animal matter is burnt, that is, it is oxidised chiefly to carbonic acid and water, which are driven off; and the mineral matter remains as a white mass which retains the form of the bone, but readily crumbles, forming the **bone ash**, consisting only of mineral matter. The mineral matter is large in amount: it forms two-thirds of the weight of dry bone. It consists chiefly of phosphate and carbonate of lime.

CHAPTER VIII

MUSCLE — MOVEMENTS

Structure of Muscle

EXAMINE the muscles of the leg of a rabbit. They are of various shapes, but are usually larger in the middle than at either end. They are attached at both ends to bones, usually by tendons. Remove a complete muscle from the limb. It can readily be divided longitudinally into bundles, and these can be split into smaller bundles, and these again by means of needles may be frayed out, or teased as it is called, into a number of fibres.

Striated Muscular Tissue. — Muscles which are larger in the middle than at the ends are divided into a belly and two extremities. The belly is usually free, while the extremities are fixed by tendons, one to one bone and the other to another, the muscle passing over at least one joint.

The upper attachment or the attachment to the less movable bone is called the **origin** of the muscle, and the lower attachment or that to the more movable bone is called the **insertion**. Sometimes there is more than one origin, the muscle arising by two or more tendons; and sometimes the attachment extends down to the belly of the muscle by the muscular fibres being attached to the bone without the intervention of tendon. Sometimes also there is more than one insertion.

The longitudinal bundles into which the whole muscle may be divided are called **fasciculi**. Each fasciculus is covered with a thin sheath of connective tissue, and the several fasciculi are connected together by connective tissue, which also forms a thin, usually transparent, sheath for the whole muscle. Each fasciculus consists of a bundle of **muscle fibres**, running longitudinally, also bound together by fine connective tissue. Each individual muscle fibre is surrounded by a transparent elastic sheath called the **sarcolemma**. If the muscle is one which ends in a tendon, as the muscle narrows the fasciculi and muscle fibres gradually end, while the connective tissue between them becomes intimately bound up with, and contributes in forming, the fibrous tissue of the tendon. The muscle fibres are about an inch in length, and lie longitudinally, dovetailed into one another along the length of the fasciculus. Examined microscopically, each fibre shows light bands alternating with dark bands running across it. These bands give it a striated appearance, so that this kind of muscle is called striated muscle. Along the fibre just under the sarcolemma are several long oval **nuclei**. If a single muscle fibre is finely teased with needles, it can be frayed out so that it splits longitudinally into finer portions called fibrillæ. Each of these fine fibrillæ also shows the light and dark transverse bands.

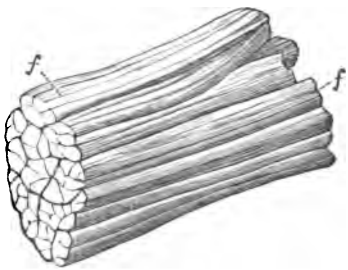


FIG. 29. — Fasciculi of striated muscle cut across.

Several fasciculi *f*, bound together into larger fasciculi to make up the muscle.

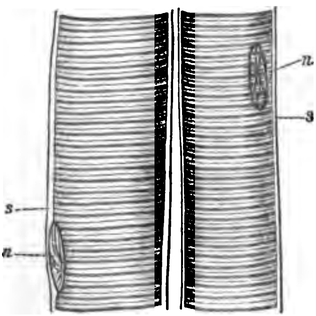


FIG. 30. — A portion of two striated muscle fibres. Highly magnified.

n, nucleus; the sarcolemma is represented by the line *s*, separated from the substance of the fibre, but no such separation in reality exists.

The muscle is well supplied with blood-vessels, which enter the muscle between the fasciculi and break up into capillaries between the fibres, these being gathered up again into veins which leave the muscle in the same way. Running near the blood-vessels are also nerves which go to the muscle fibres.

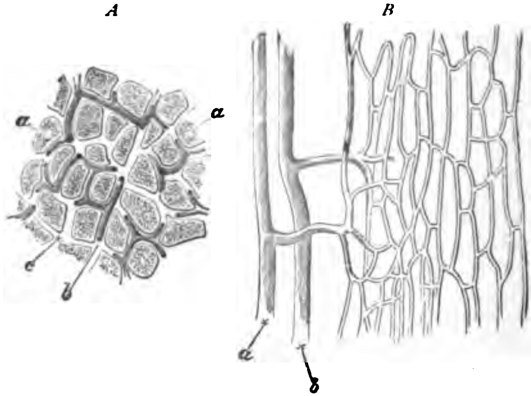


FIG. 31. — Capillaries of striated muscle.

A. Seen longitudinally — *a*, small artery; *b*, small vein.

B. Muscle fibres cut across with capillaries between them — *a*, cut ends of muscle fibres; *b*, capillaries filled with dark material injected into them; *c*, parts of capillaries not filled with injection material.

All muscles attached to bones, the skeletal muscles as they are called, consist of striated muscle fibres.

Plain Muscular Tissue. — The walls of the alimentary canal, of the arteries, of the bladder, and several other organs contain muscle fibres which are not striated, and are therefore called plain muscle fibres. The fibres of plain muscular tissue are not more than $\frac{1}{500}$th of an inch in length, being very much smaller than striated fibres. Each is a spindle-shaped cell, a

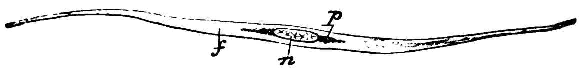


FIG. 32. — A plain muscle fibre.

f, cell substance; *n*, nucleus; *p*, granular cell substance near the nucleus.

fibre cell, containing a long oval nucleus. The cell substance is granular round the nucleus, and often shows a longitudinal fibrillation, but there is no transverse striation. The fibre has no sarcolemma, but several fibres are dovetailed into one another, forming a small bundle, and the several bundles, which may run parallel to each other, but often cross and interlace, are bound together by fine connective tissue.

Cardiac Muscular Tissue. — The muscular tissue of which the heart consists differs from both striated and plain muscular tissue. The individual fibres are like plain muscular fibres in containing a single oval nucleus and in being devoid of sarcolemma, but are short and thick, not long and narrow. They are, moreover, faintly striated transversely by light and dark bands. They are arranged end to end in columns, and each fibre or fibre cell in the column has one or two short thick branches by which it is united to the branches of the cells of neighbouring columns. The muscle cells are bound together in this way to form sheets or bundles of muscular tissue, which interlace largely, and the bundles are bound together by a little connective tissue in which blood-vessels and nerves lie.

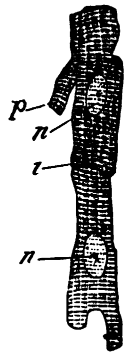


FIG. 33. — Two cardiac muscle fibres.

n, nucleus; *l*, line of junction of the two fibres; *p*, process which joined another fibre.

Muscular Movement

A movement of a limb is produced by one or more muscles drawing their ends nearer together, and in this way moving one or both of the bones to which the ends are attached. A muscle draws its ends nearer together by becoming for the time shorter, and in doing so becomes thicker or larger in the middle, for the muscle does not become smaller, or change its bulk. When a muscle has drawn its ends nearer together it is said to be **contracted**; when it has again resumed its original length and shape it is said to be **relaxed**. The contraction of a muscle is caused by the contraction of the individual muscular fibres of which it is composed, each fibre shortening in length and becoming proportionately thicker, the sum total of the contraction of these, taking place at the same time, making up the contraction of the whole muscle.

Kill a frog by cutting off the head as low down as possible.

Strip the skin off the hind legs. This is best done by cutting through the skin, and the skin only, just above the legs, and then sweeping down the skin in one piece, proceeding in the same way that a rabbit or hare is usually skinned. The muscles of the leg will then be laid bare. Any blood proceeding from torn blood-vessels should be wiped away or washed away with water containing a little salt. (0.6 per cent of salt, that is, about one-eighth of an ounce to the pint, is the best, because this is about the amount of salt present in the blood and lymph; for such a saline solution does not injure the tissues as does distilled or ordinary water.) If the muscles of the frog be not allowed to get dry, but be kept moist with this salt solution, they will remain living tissues for one or two hours.

Living Muscle and Dead Muscle. — Living muscle is semi-transparent, and varies in its redness according to the amount of blood present in its blood-vessels. It is soft and yielding to the touch, and elastic, that is, it stretches when pulled, but returns to its original length when the pull ceases. If a living muscle is pricked by a needle or sharply tapped, it will give a contraction and then at once relax again and remain quiet. Select one of the muscles of the frog, that forming the calf for instance, prick it and see that it contracts. When it contracts it becomes firmer as it increases in girth corresponding to the shortening. The hardness of the muscles of the human limbs, when they are contracted, is familiar to every one.

Dead muscle, on the other hand, is opaque. It is firm and much less yielding to the touch than living muscle. It is also less elastic. When it is pricked, tapped, or in any way treated, it does not contract, gives no response.

Out of the substance of living muscle fibres can be squeezed a thick semi-fluid substance, which soon afterwards sets into a jelly, in fact, clots like blood plasma does. This thick liquid which can be squeezed out of living muscle is called **muscle plasma**. The clot it forms consists of a substance called **myosin**, corresponding to fibrin formed from blood when it clots, and belonging like it to the class of proteids. When a muscle dies myosin is formed out of the muscle plasma. As the myosin is formed the muscle becomes cloudy and opaque. This you will see as the muscles of the frog gradually die. The myosin also causes the muscles to become firm and fixed in the position in which they are when dying, so that the body of the animal becomes stiff and rigid. This condition is called **rigor mortis**. After a few hours this stiffness passes off, the myosin being changed some little time before putrefaction commences.

The living muscle contains a proteid substance called myosinogen which forms the substance myosin, much in the same way that the blood plasma contains fibrinogen which forms the substance fibrin. Besides the myosinogen there is also some albumin in muscle, and a peculiar substance, like starch, called glycogen; and besides the salts, which are chiefly phosphates and chlorides of potassium, and in smaller amount of sodium and other metals, there are also organic bodies of which we may have something to say later on. The muscle also contains a large amount of water; about 75 per cent of the muscle is water.

During life the muscle, like the blood and the other tissues of the body, is alkaline, due to the presence of alkaline salts, but when the formation of myosin occurs and death sets in, the muscle becomes acid. This acidity is due to the formation of an acid called sarcolactic acid, not very different from the acid which is formed in milk when it turns sour.

A living muscle, like all living tissues, is constantly taking oxygen from the blood, and its complex substances are constantly breaking down into simple substances, of which carbonic acid is one of the chief. This breaking down of the substance of the muscle sets free energy in the form of heat, so that the muscle is constantly giving out heat. When a muscle contracts there is a large increase in the amount of carbonic acid which it gives off, that is to say, the breaking down of the complex substances of the muscle is much more active, and consequently a larger amount of energy is set free. Some of this energy is used to perform the work which the muscle does, the rest of it is given out as heat. The heat given out in this way when a muscle contracts is much greater than the heat given out when it is at rest.

Relation of Muscles to Nerves. — Passing to the muscles are nerves, which enter between the bundles of fibres and divide into branches. The nerves, as we shall see, are themselves bundles of delicate long "nerve fibres," and they divide in the muscle till they ultimately send a single nerve fibre to each individual muscle fibre.

Turn the frog on its belly. Separate the muscles on the back of the thigh; you will find a nerve running down the thigh to the leg, a white strand giving off a few branches as it goes. It is a little on the inner side of the middle of the back of the thigh. Pinch the nerve, the muscles below the spot will contract; this will be especially clear with the large muscle forming the calf. The nerve may be similarly excited by a hot wire, a drop of acid, or by electricity, and the muscles below will contract, that is to say, provided that you have not injured the nerve below the place at which you are exciting it. If the nerve going to a muscle is pricked, pinched, or otherwise stimulated as it is called, the muscle gives a contraction, which may be a sudden twitch and soon over, or if the stimulation is continued, may last some little time. No visible change is produced in the nerve, but some influence passing from particle to particle along it, travels quickly from the place of stimulation down to the muscle. This change which runs along the nerve is called a **nervous impulse.** The skeletal muscles performing the movements of the body are only put into action when they receive impulses coming along nerves going to them. The nerves which supply muscles and put them into action are called **motor nerves.** The nerves, as we have seen, proceed from the brain or the spinal cord. Nerves transmit impulses along their substance but do not originate them, and the impulses which the motor nerves carry when movements of the body are performed have their origin in the brain or in the spinal cord.

The Mechanism of Movement

In performing movements, one part of the body is moved towards, from, or round another part kept at rest. In a large number of movements — those involving a joint — the bone of the moving part acts as a lever, turning about that part of itself which is within the joint concerned. A lever is a bar which can be moved about a fixed point in its length. This fixed point is called the fulcrum. In a crowbar turning over a wedge (as in I. Fig. 34), the fulcrum is at the wedge on the ground, and much nearer to the weight to be raised than to the place where the man applies the power. The power necessary to raise the weight is less than the weight just in proportion to the distances of the weight and the power from the fulcrum, so that the lever is a means of increasing power. The end of the lever on which the man exerts the power moves through a greater range than the end on which the weight lies, and just in proportion to the distances of the power and the weight from the fulcrum. So that the lever is a means of

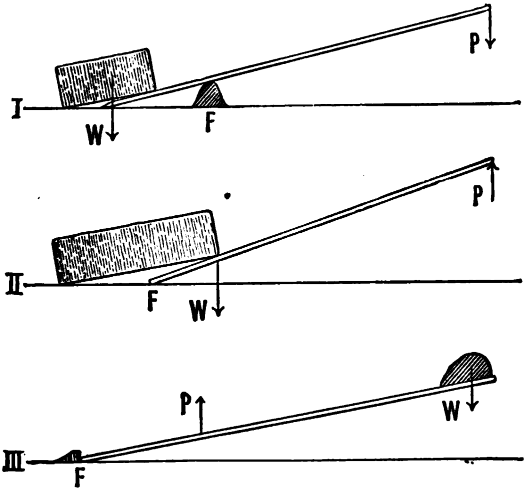


FIG. 34.—The three classes of levers.
F, fulcrum; W, weight; P, point of application of power.

changing range of motion, and if the power is applied to the short arm of the lever, of increasing the range of motion. In the human body it is the wide range of motion of the free end of a limb which is the main advantage obtained by the lever mechanism.

Levers are divided into three classes according to the position of the fulcrum:—

Class I. The fulcrum between the weight and the power.
Class II. The fulcrum at one end, and nearer to the weight than to the power.

Class III. The fulcrum at one end, but nearer to the power than to the weight.

Let us examine a few of the movements of the body.

Bending or Flexion of the Forearm.—This is caused by the action of the biceps muscle, the large muscle on the front of the arm. The biceps muscle is attached by two tendons to the scapula, close to the articular cup for the humerus. This forms its origin. It has a large belly which lies on the front of the humerus, but is not attached to it. Just above the elbow joint the muscle narrows and passes into a tendon which, passing

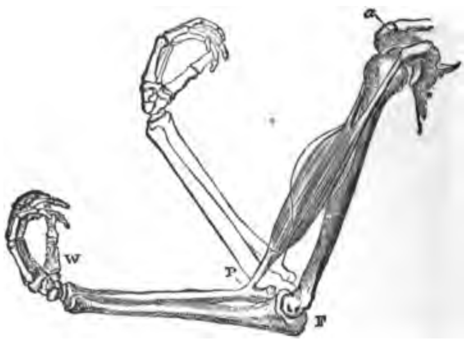


FIG. 35.—Diagram to show the action of the biceps muscle of the arm.

The two tendons by which the muscle is attached to the scapula are seen at *a*; P, the point of attachment of the muscle to the radius; F, the elbow joint; W, the weight of the hand.

over the joint, is attached to the radius at a rough elevation, nearly one and a half inch below the head of the radius. When the muscle contracts, the radius, and with it the ulna, is drawn up towards the scapula, and so the forearm is bent on the arm, the radius and ulna turning as on a hinge at the lower end of the humerus. The arrangement is that of a lever of the third class. The fulcrum is at the elbow joint; the weight is the radius and all that is attached to it, the arm, the hand and any object in it; and the power is applied by the muscle between the weight and the fulcrum, but close to the latter. Since the biceps muscle is inserted into the radius close to the elbow joint, a small diminution in length of the muscle will produce a large movement of the hand carried at the end of the radius. In forcible flexion of the arm, it is necessary for the scapula to be fixed, and this is done by the simultaneous contraction of muscles passing to it chiefly from the spine.

Straightening or Extension of the Forearm.—The bent arm is straightened by the action of the triceps muscle, situated on the back of the arm. The triceps muscle arises partly by a tendon attached to the scapula, and partly by two other portions attached to the posterior surface of the humerus. Just above the elbow joint the muscle narrows to a tendon which is inserted into the extreme upper end of the ulna, the process of the bone which is distinctly felt at the elbow. The ulna articulates with the humerus more than one inch below this. When the muscle contracts it draws the upper end of the ulna upwards, and so straightens the arm. The arrangement is that of a lever of the first class. The weight is at the hand at the one end of the ulna, the power is applied by the muscle to the other end of the ulna, and the fulcrum is at the elbow joint between the two, but close to the insertion of the muscle.

Flexion of the Leg at the Knee Joint.—The leg is bent by the action of the flexor muscles situated on the back of the thigh, the chief of these being called the biceps of the leg. Its origin is double, arising as it does from the hip bone by a tendon, and from the thigh bone by the direct attachment of muscle fibres to the bone. The lower tendon passes over the back of the knee joint, and is inserted into the upper end of the fibula, at about two inches below the joint. The arrangement is that of a lever of the third class, the fulcrum being at the knee joint, the weight being the leg and foot, and the power being applied just below the fulcrum.

Extension of the Leg at the Knee Joint.—The leg is straightened, as in kicking, by the four extensor muscles lying on the front of the thigh. The most important of these arises by tendinous attachments from the hip bone above the socket for the femur, passes over the hip joint, its belly lying on the front of the thigh, and narrows below to a tendon which is inserted into the patella, which is in its turn attached by a strong ligament to the front of the tibia, about two inches below the knee joint. The arrangement is also that of a lever of the third class. The leg and foot form the weight, the fulcrum is at the knee joint, and the power is applied between the two, but close to the fulcrum.

Movements at the Ankle Joint. — The ankle joint is a hinge joint allowing flexion and extension. Extension is produced by the muscles of the calf, which arise partly from the lower end of the femur, but chiefly from the upper part of the tibia and fibula; they form the large belly of muscle of the calf, and are inserted by a long and powerful tendon into the heel bone. Flexion is produced by the muscles lying just on the outer side of the shin bone (tibia) on the front of the leg.

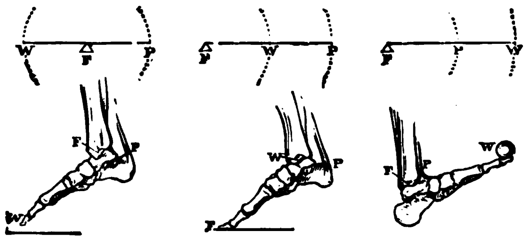


FIG. 36. — Diagram of the actions of the ankle joint.
I., II., III., as a lever of the 1st, 2nd, and 3rd class.

The main muscle arises from the upper part of the tibia, and is inserted into the bones of the foot in front of the ankle joint. Movements at the ankle joint illustrate the three classes of levers.

I. When, the heel being raised from the ground, the foot is extended, so that the toes tap the ground, the weight or resistance is at the toes, the power is applied by the calf muscles at the heel, the fulcrum being at the ankle joint between the two. Lever of the 1st class.

II. When the body is raised on the toes, the fulcrum is at the toes, the power is applied by the calf muscles at the heel, and the weight is that of the whole body, which falls on the foot at the ankle, between the heel and the toes. Lever of the 2nd class.

III. When the foot is bent, as in raising the toes, the fulcrum is at the ankle joint, the weight of the toes, and the power applied by the flexor muscles between the two. Lever of the 3rd class.

Other examples of lever mechanisms in the body are: —

Levers of the 1st Class. — The nodding movement of the head backwards and forwards on the atlas as the fulcrum. Raising the body from the stooping position, with the fulcrum at the hip joints.

Lever of the 2nd Class. — When one thigh is kept bent up towards the body as in hopping; the fulcrum in this case is at the hip joint, the power (mainly due to the extensor muscles on the front of the thigh) is applied at the knee, and the weight of the limb falls between the two.

Levers of the 3rd Class. — Movement of the lower jaw upwards in mastication. Raising the body from the recumbent to the sitting posture; the fulcrum in this case is at the hip joints, the weight is that of the head and body, and the power is applied by the muscles passing from the front part of thigh to the hip bones.

Walking. — In walking one foot is placed on the ground in front before the toes of the other foot have left it. The leg is stepped forward chiefly by the action of the muscles passing from the pelvis to the front of the thigh; and the knee is slightly bent by the action of the muscles of the back of the thigh, to enable the toes to clear the ground. The body is then raised on the toes of the leg that is behind and lifted forward. This is chiefly done by the action of the muscles of the calf raising the weight of the body, which meets the foot at the ankle joint, the fulcrum being at the toes; in fact, this part of the act is that of a lever of the second class described above. In easy walking very little effort is required, for a leg can swing like a pendulum, that is, at a rate in accordance with its length, the longer the pendulum the slower the rate of swing. This explains why it is that, when walking at a natural step, a short-legged man naturally takes quicker steps than a long-legged man.

Running. — In running both feet are off the ground at the same time for a moment in each step. The muscles contract more powerfully and quickly, the thrust forward of the body being accomplished not only by the contraction of the muscles of the calf, but also by the powerful action of the extensor muscles of the leg, straightening the bent knee of the forward leg.

FIG. 37.—Diagram indicating some of the muscles which tend to keep the body erect.
I., muscles of calf; II., of back of thigh; III., of spine.
1, muscles of front of leg; 2, of front of thigh; 3, of abdominal wall; 4, 5, of front of neck. The arrows indicate the direction of action of the muscles.

The Erect Position.—The erect position of the body is maintained by the contraction of certain muscles, and by the tension of certain ligaments at the joints. A dead body cannot be made to stand erect without artificial support. In a man standing upright the feet form the fixed support, and the muscles which keep him from falling forwards or backwards act from the feet as fixed points and keep in the right position the segments of the body above them. The leg is kept over the ankle, so that the body does not fall forwards or backwards, by the action of the muscles passing from the back and of those passing from the front of the leg to the foot. The set in front, acting from the foot as the fixed attachment, would tilt the leg forwards, and the set behind would tilt it backwards. These two sets contract at the same time so as just to balance each other, and so the leg is kept erect.

The knee is kept straight in a more simple way, the chief muscles acting being those in front of the thigh, the extensor muscles, which by contracting keep the knee from bending, and so prevent the body from falling backwards. The leg cannot be extended beyond the straight line, or the knee be bent the wrong way, on account of the ligaments of the joint, so that in this case it is not necessary for the flexor muscles to act in order to balance the action of the extensor muscles.

The trunk is supported on the thigh bones at the hip joints by the balancing of the muscles passing from the trunk to the thighs in front and behind. The trunk is somewhat heavier behind the hip joints than in front of them, and so the tendency is to fall backwards, but this is prevented chiefly by a strong ligament passing from the pelvis to the thigh bone, over the front of the hip joint. The head is supported on the trunk and prevented from falling forward partly by ligaments passing from the back of the head to the spinal column. These ligaments are very strong in quadrupeds, as in the horse for example. But it is by the contraction of the muscles at the back of the neck that the head is supported in exactly the right position. Directly a man, in a sitting posture, falls asleep, the head falls forwards. This is because the contraction of the muscles at the back of the neck is no longer maintained. How was the contraction maintained? By the brain, but this during sleep is at rest, and no longer acting on the muscles. Again, if a man receives a violent blow on the head, he will fall "in a heap," with his limbs flaccid and powerless. All the muscles which were keeping him upright have suddenly ceased their contractions. The muscles are not injured, and after a time, the man will "return to himself," regain consciousness, and be able to stand upright as before. The blow on the head produced a "shock" to the brain and spinal cord, and they ceased for a time to keep the muscles contracted. The muscles, then, do not contract of "their own accord," but only by the influence of the central nervous system. The central nervous system is in connection with the muscles by means of nerves, and the muscles are controlled by means of impulses sent along the nerves from the brain or spinal cord.

CHAPTER IX

THE HEART

PROCURE a sheep's heart from a butcher with the "bag," that is the pericardium, and the lungs, if possible, still attached. If not, see at least that the point at which the vessels have been cut is some distance from the heart.

The Pericardium. — The pericadium is a completely closed bag in which the heart lies. It is formed of a thin membrane which is transparent except near the large vessels, where it is thickened by the presence of fat. When the bag is cut open a little yellowish fluid, the pericardial fluid, may escape. The heart hangs free in the bag, the pericardial membrane being apparently attached only to the base of the heart, or rather to the roots of the great vessels. The inner side of the membrane is smooth and shiny, and the same is the case with the surface of the heart. This is because the pericardium at the base of the heart passes on in a thin layer over the whole heart, firmly adhering to it, so that there are two parts of the pericardium, one applied to the heart, and the other forming a bag, and the one part is continuous with the other at the base of the heart.

The Heart. — The heart is conical in shape and muscular in nature, and contains four chambers. The base to which the vessels are attached is uppermost; the apex is lowermost. You can tell the front because it is rounded and convex, and has a groove filled with fat running from the upper part on one side, obliquely downwards towards the other side. The back is flatter than the front, and the groove containing fat running down the middle of it is inconspicuous. Place the heart before you with the front uppermost and the apex pointing away from you, the left side of the heart will then be on your left hand. Notice that the left side, including the whole of the apex of the heart, is firm and unyielding, while the right side is soft and flabby.

On each side of the base of the heart there is situated a flat ear-like structure, and the wall of the part of the heart on

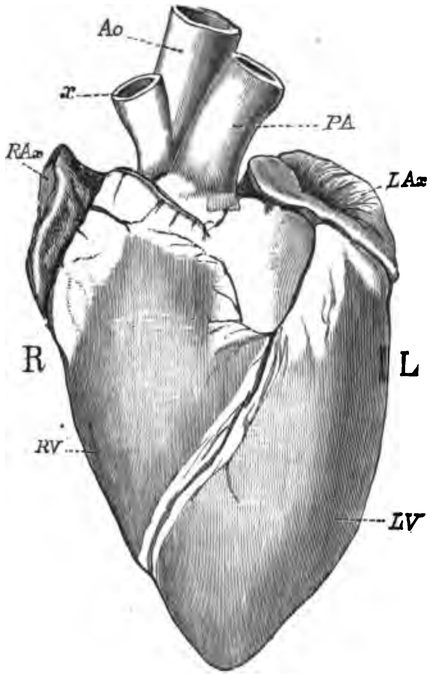


FIG. 38.—The sheep's heart. Front view.

R, right side; L, left side; *RV*, right ventricle; *LV*, left ventricle; *RAx*, appendix of right auricle; *LAx*, appendix of left auricle; *PA*, pulmonary artery; *Ao*, aorta; *x*, its first large branch.

which each rests is soft and thin. These are the **right auricle** and the **left auricle**, as the two upper chambers are called. Each of the ear-like structures is called the appendix of the auricle, right or left as the case may be. Just below the two appendices, running from side to side across the front and across the back of the heart, is a groove occupied by a large quantity of fat. This groove marks the separation between the two auricles above and the two ventricles, as the lower chambers are called, situated below. On the

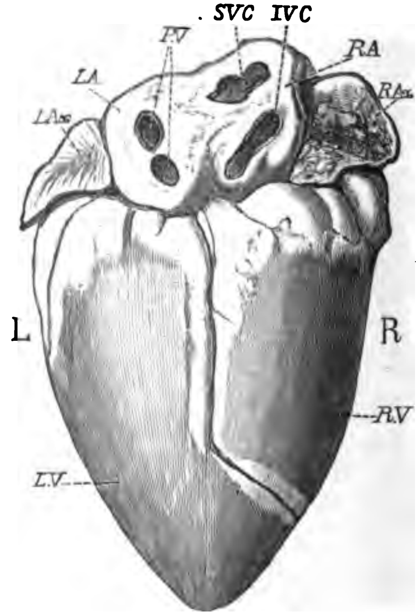


Fig. 39. — The sheep's heart. Back view.

R, right side; L, left side; *RV*, right ventricle; *LV*, left ventricle; *RA*, right auricle; *RAx*, its appendix; *LA*, left auricle; *LAx*, its appendix; *SVC*, opening of superior vena cava; *IVC*, opening of inferior vena cava; *PV*, opening of pulmonary veins.

right side, the rather thin wall of the **right ventricle** can be picked up between the thumb and finger, so that one can tell distinctly that there is a cavity inside. On the left side, the wall of the **left ventricle** is so thick that it cannot be picked up in this way. The heart then consists of the four chambers, the right and left auricles above, and the right and left ventricles below.

On the back of the heart, in the middle line, just above the transverse mass of fat, lies a thin collapsed tube, the **inferior vena cava.** The vessel may have been cut off short, in which case its opening only will be seen. If the little finger be gently passed into this opening, its tip will be felt to reach inside the right auricle. Make the opening a little larger with scissors; then put the finger into the right auricle again and pass it straight upwards till it comes out of another opening at the top of the auricle. This is the opening of the **superior vena cava.** More or less length of this vessel may be present. There are no other vessels opening from without into the right auricle. Put the finger into the right auricle and pass it downwards, the tip of the finger will go through the opening into the right ventricle and can be felt to be inside that chamber.

Just to the left of the inferior vena cava is an opening leading into the left auricle. It is the opening of one of the **pulmonary veins.** Put your little finger or a penholder into it, and passing it upwards feel for another opening; if you find one, it will be that of the other pulmonary vein. There are in the sheep two pulmonary veins, one bringing blood from the right lung and one from the left lung, but sometimes they unite into one vessel just before they open into the left auricle. In man there are four pulmonary veins, two coming from each lung, and they all open separately into the left auricle.

The tip of the finger can be passed down from the left auricle into the left ventricle. The wall of the left ventricle will then be felt to be very thick. You cannot pass your finger from one auricle to the other or from one ventricle to the other, for the two auricles are completely separated from each other, and the two ventricles are completely separated from each other by a partition running through the heart, dividing the right side from the left. On the right side there is an opening leading from the right auricle to the right ventricle, and on the left side an opening leading from the left auricle to the left ventricle.

Cut open the right auricle from the inferior vena cava to the superior vena cava, and notice that the wall is thin and smooth on the inside except in the appendix, and there it is very irregular and formed into small pits by the wall having thickened bands. Open the left auricle in a similar way. Its wall has a similar appearance. Notice the partition or **septum** which divides one auricle from the other; in

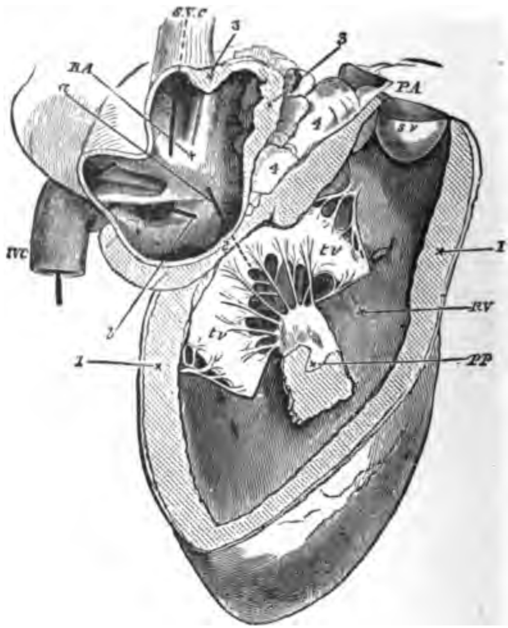


FIG. 40.—The right side of the heart of a sheep laid open.

RA, right auricle; *RV*, right ventricle; *S.V.C*, superior vena cava; *IVC*, inferior vena cava; a bristle is passed through each of these; *tv*, two of the three flaps of the tricuspid valve, the third is dimly seen behind them. Between the flaps chordæ tendineæ are seen proceeding to a papillary muscle, *pp*, which is shown cut away from the wall of the ventricle. *PA*, pulmonary artery; *sv*, one of the three pockets of the semilunar valve. 1, The wall of the right ventricle; 2, the ring between the auricle and ventricle, with *a*, a bristle passed through the opening; 3, wall of the right auricle; 4, fat lying between the auricle and pulmonary artery; *b*, a bristle passed into the coronary vein.

one part this is very thin. Gently wash away any clots of blood there may be. Look down into the right ventricle; at first sight there does not seem to be anything separating it from the right auricle. Hold up the heart by the right auricle with both hands and get some one to pour water through it into the right ventricle till it runs over, and then to press gently the wall of the right ventricle with the finger; three flaps of membrane at once spring out from the sides, and meeting one another in the middle, completely shut off the ventricle from the auricle. These three flaps of membrane form a valve called the **tri-**

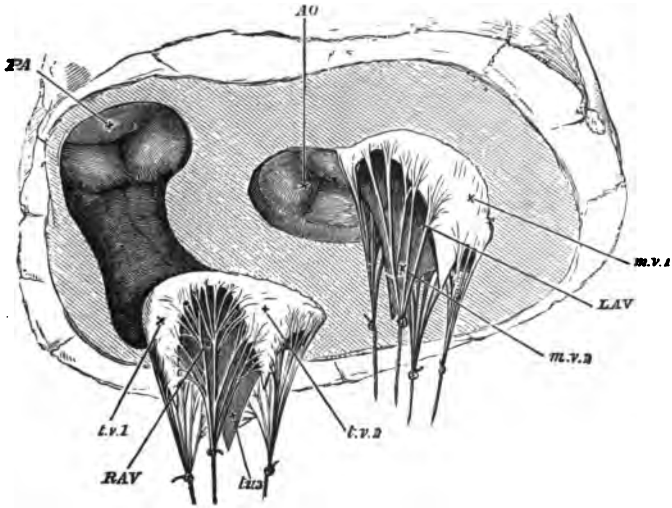


FIG. 41. — View of the orifices and valves of the heart from below, the whole of the two ventricles being cut away.

Ao, aorta; *PA*, pulmonary artery, each with its three cups of the closed semilunar valves seen convex from below; *RAV*, opening between the right auricle and right ventricle, surrounded by the three flaps, *t.v.*1, *t.v.*2, *t.v.*3, of the tricuspid valve with chordæ tendineæ between them, to which three cords are tied, taking the place of the papillary muscles; *LAV*, opening between the left auricle and left ventricle, with the two flaps, *m.v.*1, *m.v.*2, of the mitral valves and chordæ tendineæ, to which cords are tied.

cuspid valve. The valve bulges up when you press the ventricle because it will not allow fluid to pass from the ventricle to the auricle. Do the same thing on the left side, and you will find two flaps of membrane separating the left ventricle from the left auricle. This valve is called the **bicuspid or mitral valve.**

Pinch up the wall of the right ventricle at its lowest part, close to the apex of the heart, and cut the chamber open with scissors. Go on cutting upwards a short distance, at the front and at the back, keeping on the front of the heart close to the oblique groove, and on the back of the heart close to the

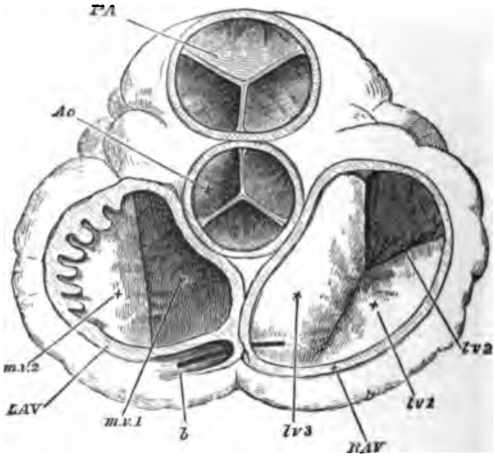


FIG. 42. — View of the orifices and valves of the heart from above, the auricles and vessels being cut away.

Ao, aorta; *PA*, pulmonary artery, each with its closed semilunar valves; *RAV*, opening between right auricle and right ventricle, closed by the three flaps *lv1*, *lv2*, *lv3*, of the tricuspid valve; *LAV*, opening between left auricle and left ventricle, closed by the two flaps *m.v.1*, *m.v.2*, of the mitral valve; *b*, bristle passing into coronary vein.

middle vertical groove, until the cavity is laid well open. The wall of the right ventricle is thicker than that of the auricles, and the inner surface is more uneven. The three flaps of the tricuspid valve will be seen hanging down. Each flap is a thin transparent membrane, roughly triangular in shape, fixed to the wall of the ventricle above, and with its tip hanging down below. Attached to the sides and tip of each flap are several thin white cords passing from it to little projections or columns on the walls of the ventricle. The cords are called **chordæ tendineæ**, and the columns **papillary muscles**. The chordæ tendineæ are to prevent the flaps from being forced back so far as to give way. At the top of the right ventricle, towards the front of the heart, is a vessel leaving the right ventricle. This is a large, thick-walled vessel, not collapsed, called the **pulmonary artery**. It carries the blood from the right ventricle to the lungs, and lies the farthest in front or most anterior of all the vessels at the base of the heart. Cut it open for a short distance. Just where it leaves the ventricle three half-moon-shaped flaps of transparent membrane are arranged round the inside of the vessel. Each flap forms a pocket open on the side away from the ventricle. From their half-moon shape these are called the **semilunar valves**. The valves will allow blood to pass from the ventricle into the artery, but not back again. Hold the heart under a tap so that water runs down the artery towards the ventricle; the pockets will fill and swell out, and if you close up the artery again you will see that they meet one another and block the way from the artery to the ventricle.

Open the left ventricle by cutting with a knife just on the left of the oblique groove in front, and carry the knife round the tip and up the back. The wall of the left ventricle is more than half an inch thick. The partition or septum between the two ventricles is also about half an inch in thickness and muscular like the rest. The cavity of the left ventricle seems to be smaller than that of the right, but there is really very little difference, if any, when both are filled, because the septum bulges into the right ventricle and so makes its cavity smaller than it appears to be when empty. The two flaps of the mitral valve hang down on each side of the opening from the left auricle into the left ventricle. Each flap is a transparent but tough membrane, from the edges of which the white cords, the chordæ tendineæ, pass to thick muscular projections, the papillary muscles, situated on the wall of the ventricle. At the top of the ventricle, between the mitral valve and the septum, is the opening of the **aorta**. Put your finger into this and see which of the vessels at the base of the heart it is. Notice that it is large, thick-walled, and not collapsed. It carries the blood to all parts of the body except the lungs. It gives off a large branch on the right side almost at once. There are semilunar valves at its commencement from the left ventricle just like the semilunar valves at the origin of the pulmonary artery from the right ventricle. Hold the aorta under a tap and let the water run gently down it towards the ventricle. Notice that the three pockets of the semilunar valve swell out, and meeting in the middle, block the way so that the water will not run in. The valve will allow blood to pass from the left ventricle into the aorta, but not back again. Cut open the aorta with scissors, from the ventricle upwards, and see that the pockets of the semilunar valve open away from the ventricle towards the artery. Behind each of two of the pockets is a small opening from the aorta. These are the openings of two arteries which give branches to the substance of the heart itself. They are called the **coronary arteries.** After the blood which these carry from the aorta has been sent through the capillaries in the substance of the heart it flows back into the right auricle by a vein, the **coronary vein,** which has a rather large opening into that chamber just below the septum between the auricles. Some of the coronary vessels can be seen running in the grooves on the surface of the heart. We have seen that there are valves where each auricle opens into its corresponding ventricle, and where each ventricle opens into the artery leaving it; there are, however, none where the veins open into the auricles.

The Human Heart.—The human heart is a little smaller than that of the sheep, being about the size of the person's fist. It does not differ in any important respect from the heart of the sheep except that there are four pulmonary veins opening into the left auricle instead of two; so that the description given is true also for the heart of man.

The Tissues of the Heart.—The heart is, as we have seen, composed of muscular tissue of a special kind. This is covered on the outer side by the thin shining membrane, the visceral layer of the pericardium, closely adherent to the muscular tissue. On the inner side the muscular tissue is covered, and so the chambers of the heart lined, by a thin transparent membrane, called the **endocardium,** which is also closely adherent to the muscular tissue. The valves are formed of tissue of the same nature as connective tissue, thin but strong, and are covered by the endocardium, which passes over them closely adherent to their thin tissue, so that there is a layer of endocardium on both sides of the valves. At the openings of the veins and arteries the endocardium is continuous with a similar delicate membrane forming the innermost layer of the veins and arteries.

The Action of the Heart

Contraction of the Muscle Fibres of the Heart. — The cardiac muscle fibres contract like other muscle fibres; that is, they become shorter and correspondingly thicker. Since they form the walls of a cavity, when they contract they cause a diminution in the size of the cavity, the wall of the cavity becoming thicker. When an india-rubber ball is squeezed, the cavity becomes smaller, and the air or water in it is driven out; the cavity becomes smaller because a portion of the wall is pushed into it, but the wall itself does not change in extent or in thickness. When the heart contracts the walls diminish in extent and increase in thickness. Moreover, in each chamber of the heart the fibres comprising the walls are arranged in bundles in a complicated manner, passing from one part of the wall round the chamber to another part, so that when they contract they draw one side of the wall in till it meets the opposite side. In this way the cavity of the chamber is obliterated, or nearly obliterated, and all, or nearly all the blood in it driven out.

A Beat of the Heart. — A beat of the heart is the contraction of the walls of the auricles and of the ventricles. The two auricles contract at the same time, and then immediately afterwards the two ventricles contract at the same time, then there is a pause during which the auricles and ventricles are both relaxed; then a contraction of the auricles occurs again, followed immediately by a contraction of the ventricles, and then there is another pause, and so on. The two auricles always contract together, and the two ventricles always contract together, so that the events taking place in the heart on the left side are similar to those taking place on the right side.

Let us consider the right side first. The right auricle receives its blood from the superior vena cava and the inferior vena cava. When it becomes full the right auricle contracts and drives the blood into the right ventricle. The auricle begins to contract just round the openings of the veins, so that it squeezes together their flaccid or easily collapsed openings, and then the contraction runs over the whole auricle towards the opening into the ventricle. The blood, owing to this, cannot get back into the veins but is forced into the ventricle. The right ventricle thus filled with blood at once begins to contract. One of the first effects of the pressure thus set up is to force blood behind the flaps of the tricuspid valve; this brings the flaps together and so closes the way back to the auricle. When the walls of the ventricles contract, the papillary muscles forming part of the walls contract also, and thus tighten the chordæ tendineæ attached to them; these pull on the flaps of the tricuspid valve, and prevent them from being forced back into the auricle. The contraction of the ventricle very soon exerts enough pressure to force open the semilunar valves of the pulmonary artery, and then it drives the blood into that vessel. It cannot open the semilunar valves at once, because the pulmonary artery is already full and distended with blood. Soon the ventricle gets up enough pressure to open them, and keeps strongly contracting till it has forced its blood into the artery. This it does partly by forcing the blood in the pulmonary artery farther along into the lungs, and partly by distending the artery still more, so as to make room for the fresh quantity of blood. When the ventricle has emptied, or nearly emptied itself, it begins to relax. The pockets of the semilunar valve are full of blood, and now the great pressure of the blood in the pulmonary artery presses them together and closes the way so that no blood flows back into the ventricle. While the ventricle is contracting the auricle relaxes and the blood flows into it again from the veins. This goes on till the auricle is full, then it contracts and drives the blood into the ventricle, which by this time is relaxed, and the same events occur again. More and more blood is thus driven by the right ventricle into the pulmonary artery, so that the blood which is already in the artery must be forced on through the branches of the artery and through the capillaries of the lungs, and along the veins from the lungs back to the left auricle. It is the force of the right ventricle alone which drives the blood round the pulmonary circulation back to the left auricle.

The blood flows from the pulmonary veins into the left auricle, and when the left auricle is full it contracts in the same manner and at the same time as the right auricle, driving the blood into the left ventricle. The left ventricle then contracts in the same manner and at the same time as the right ventricle. Directly its contraction begins the blood is forced behind the

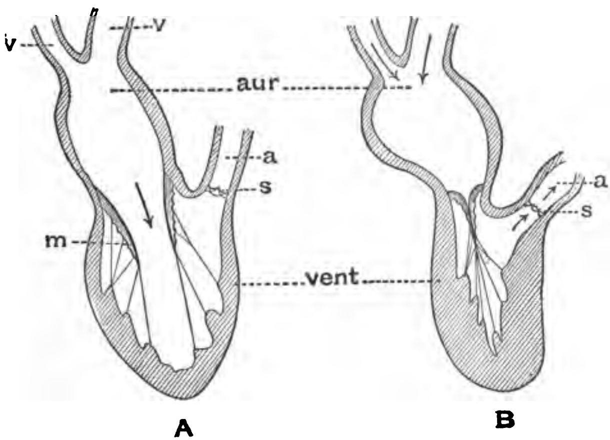


FIG. 43.—Diagram to illustrate the action of the heart.

aur, auricle; vent, ventricle; v, veins; a, aorta; m, mitral valve; s, semilunar valves.

In A, auricle contracting, ventricle dilated, mitral valve open, semilunar valves closed. In B, auricle dilated, ventricle contracting, mitral valve closed, semilunar valves open.

flaps of the mitral valve, pressing the flaps together and so blocking the way back to the left auricle. The papillary muscles contract also, tightening the chordæ tendineæ in the same way as in the right ventricle. Soon the contraction of the left ventricle has got up enough pressure to open the semilunar valves of the aorta and then it forces the blood into the aorta. When it has nearly or quite emptied itself it relaxes, and the semilunar valves of the aorta are closed by the great pressure in the aorta keeping the pockets pressed together so that no blood returns to the ventricle.

The aorta with its branches is distended with blood, and as more and more blood is forced into it by the left ventricle, the distension is kept up and some of the blood already in it is forced along the branches, and so through the capillaries in all parts of the body (except the lungs) into the veins, and finally along the inferior or superior vena cava to the right auricle. The left ventricle forces the blood all the way from the heart through all parts of the body (except the lungs) back to the heart again. Much greater force is required to do this than to send the blood only through the lungs, because it has to drive blood through a much larger number of capillaries. The walls of the left ventricle are therefore much thicker than those of the right.

The Cardiac Impulse. — The apex of the heart lies close to the chest wall, and with each beat of the heart is suddenly pressed against it. This striking of the chest wall by the apex of the heart is called the cardiac impulse. It is easily felt if the finger is placed on the chest between the fifth and sixth ribs on the left side, about one inch below and half an inch to the inner side of the left nipple.

Sounds of the Heart. — Listen to the beat of the heart of a person by putting the ear against the chest just where the cardiac impulse is felt. Two sounds are heard — the first dull and relatively long, the second short and sharp; the two may be likened to the syllables "lub," "dŭp." The two sounds succeeding each other very rapidly are followed by a relatively longer but still brief pause, and then repeated again. The first sound, the "lub," occurs when the ventricles are contracting, and is caused partly by the "rumbling" of the muscular tissue and partly by the vibrations of the mitral and tricuspid valves set up by the pressure on them. The second, sharp sound, the "dŭp," is caused by the semilunar valves of the aorta and pulmonary artery being thrown into vibrations at their sudden closure. This second sound is heard louder if the ear is placed on the chest over the aorta at the level of the second costal cartilage.

Rate of Beat. — The heart beats about 72 times a minute, but its rate varies in different individuals. It is generally quicker in women than in men. The heart beats more quickly when work is being done because the tissues need more blood.

Course of the General Circulation. — The aorta, leaving the ventricle and giving off the coronary arteries, first forms an arch, the arch of the aorta, from which, in man, three large branches are given off. The first of these, a large one on the right side, immediately divides into two, one of which, called

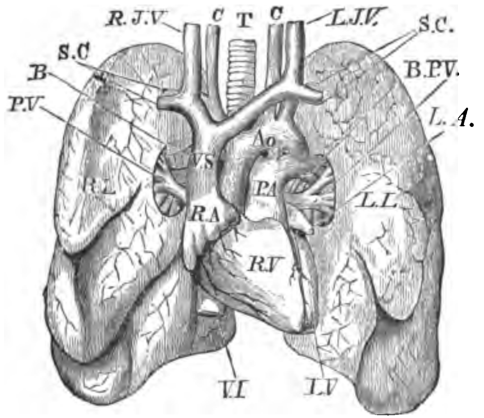


FIG. 44. — Front view of the heart, great vessels, and lungs.

R.V, right ventricle; *L.V*, left ventricle; *R.A*, right auricle; *L.A*, left auricle; *Ao*, aorta curving backwards to the left; *V.S*, superior vena cava; *V.I*, inferior vena cava; *C*, carotid arteries; *R.J.V*, *L.J.V*, right and left jugular veins; *S.C*, subclavian vessels, artery and vein on each side; *R.L*, *L.L*, right and left lungs; *P.A*, pulmonary artery dividing into two; *P.V*, pulmonary veins; *T*, trachea; *B*, bronchi. All the vessels except those of the lungs are cut.

the **right subclavian artery**, goes to the right arm, while the other, called the **right carotid artery**, goes to the right side of the neck and head. The aorta then gives off from the arch the **left carotid artery** to the left side of the neck and head, and farther on the **left subclavian artery** to the left arm. Continuing to arch backwards towards the spine, the aorta runs downwards through the thorax, giving off branches to the walls of the thorax and to the bronchial tubes of the lungs, and piercing the diaphragm enters the abdomen. In the abdomen it gives branches to all the abdominal organs and to the walls of the abdomen, and then divides into two main arteries, one for each leg.

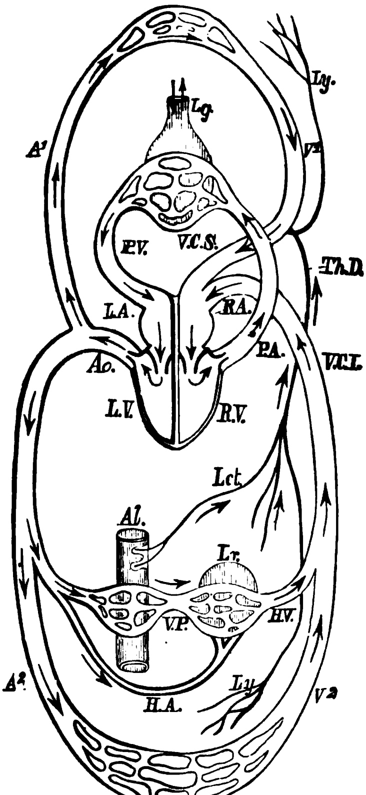


FIG. 45.—Diagram of the course of the circulation represented as viewed from behind.

L.A., left auricle; *L.V.*, left ventricle; *Ao*, aorta; A^1, arteries to upper part of body; A^2, arteries to lower part of body; *H.A.*, hepatic artery to liver; V^1, veins of upper part of body; V^2, veins of lower part of body; *V.P*, portal vein; *H.V*, hepatic vein; *V.C.I*, inferior vena cava; *V.C.S*, superior vena cava; *R.A.*, right auricle; *R.V.*, right ventricle; *P.A.*, pulmonary artery; *P.V.*, pulmonary vein; *lg*, lungs; *Al*, alimentary canal; *Lr*, liver; *Ly*, lymphatics; *Lct*, lacteals; *Th.D*, thoracic duct. The arrows indicate the course of the blood and lymph. The vessels carrying arterial blood have thick outlines, those carrying venous blood have thin outlines. The capillaries are represented by the network of tubes between the arteries and the veins.

The figure is a mere diagram or plan of the course of the circulation, and does not show the manner in which the vessels branch or the distribution of the branches.

The veins bringing the blood back from the arms unite to form the **right** and **left subclavian veins**, and the veins of the head and neck unite to form veins the largest of which are the **external jugular veins**, one on each side. The subclavian, jugular, and other veins of each side unite, and the two large veins so formed join to form the superior vena cava, which empties its blood into the right auricle. The large veins from the legs unite to form the inferior vena cava, which passes up the abdomen, receiving the veins from the kidneys, and close below the diaphragm a large vein, the **hepatic vein**, from the liver; it then pierces the diaphragm and reaches the right auricle. The veins from all the other abdominal organs, namely, the stomach, the small intestine, the large intestine, the spleen, and the pancreas, unite to form a large vein called the **portal vein**. The portal vein runs to the liver. In the liver the portal vein breaks up into capillaries, and its blood mingles with the blood brought to the liver direct from the aorta. The blood flows from the liver by the hepatic vein to the inferior vena cava. So that the blood from these abdominal organs only reaches the inferior vena cava to return to the heart, after it has passed through a second set of capillaries in the liver.

Observation of the Beat of the Heart of the Frog. — Kill a frog by cutting off its head. With a pair of scissors cut through the skin and the sternum exactly in the middle line in front. The heart will then be seen. The heart, like the other tissues of the frog, remains living for some time after the death of the animal, and will continue to live when even cut out of the body. Observe the beating of the heart. The two auricles contract and then immediately the ventricle (there is only one ventricle in the frog). The auricles, which are red in colour, the right one being dark, become suddenly paler when they contract, as the blood in consequence is driven out of them into the ventricle. Similarly when the ventricle contracts it becomes smaller and paler as the blood is driven out of it into the arteries. In the frog there are two other contractile parts, viz. (1) the ends of the great veins, which are dilated, forming a venous chamber called the sinus venosus just before they open into the auricles, and (2) the root of the great arteries, or bulbus arteriosus. The sinus venosus contracts first, then the two auricles together, then the ventricle, and then the bulbus arteriosus.

CHAPTER X

STRUCTURE AND PROPERTIES OF BLOOD-VESSELS — REGULATION OF THE CIRCULATION — LYMPHATICS

Structure of Blood-Vessels

THE internal layer of the blood-vessels, a membrane continuous with the endocardium lining the interior of the heart, is called the **endothelium.** It is continuous throughout the arteries, capillaries, and veins. The endothelium consists of flat, very thin cells, united together at their edges to form a thin membrane.

Capillaries. — The smallest vessels, the capillaries, which vary a good deal in width, and may be only $\frac{1}{3000}$th of an inch wide, have this thin membrane for their wall, and nothing else. A capillary, in fact, consists of thin, flat cells, united together at their edges to form a tube. These cells are longer than they are broad; in each cell lies a flattened nucleus. From this sim ple structure there is a gradual transition with increasing thickness of the wall to the large arteries on the one side and to the large veins on the other.

Arteries. — The smallest arteries have their walls strengthened by the presence of a few plain, muscular fibres placed round outside the endothelium. The plain muscular fibres are small spindle-shaped cells, each with its long nucleus, and are wrapped round the endothelium across the length of the vessel. As we trace these smallest arteries back until they join to form arteries larger than themselves, but still so small that a microscope is required to see them, we find that the muscle fibres have increased in number, till they form a definite layer, a muscular coat, as it is called, round the endothelium; and there is, in addition, a little, fine connective tissue outside this. In arteries still larger the muscular coat becomes still thicker and consists of several layers, between which are layers composed of networks of elastic fibres, and there is a special layer of this elastic material immediately outside the endothelium. Outside the muscular coat the connective tissue layer is also thicker. So that the wall of an artery consists of three layers: (1) the endothelium on the inner side, with a thin elastic layer on the outer side of it; (2) the muscular and elastic coat; (3) the connective tissue coat on the outer side.

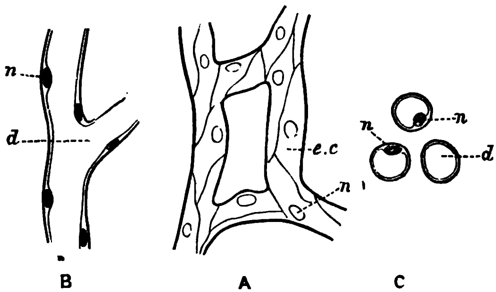


FIG. 46. — Capillaries.

A, surface view; B, cut lengthwise; C, cut across; *e.c*, endothelial cells; *n*, nuclei; *d*, the lumen or bore.

The large arteries, especially the aorta, contain, as compared with smaller arteries, much elastic tissue in proportion to muscular tissue. Owing to the presence of this elastic tissue, all the arteries are elastic; they yield when pulled, and go back to their former condition when let go. When fluid is driven into them they distend, and when the fluid is let out, shrink again.

Veins. — The walls of veins are in structure similar to the walls of arteries, and consist as a rule of the same three layers. The walls are not so thick as those of arteries, for there is much less elastic tissue and less muscular tissue than there is in arteries, though there is more connective tissue. When a vein is cut across the vessel collapses, that is, the thin walls fall together. When an artery is cut across the vessel does not collapse, because the walls are thicker and contain much elastic tissue, which keeps the vessel open.

Blood Pressure

The aorta and its branches form, then, a system of elastic tubes, which lead through an enormous number of very fine tubes, the capillaries, into wider tubes again, the veins. The blood has to be forced through an enormous number of capillaries, some of which are, as we have seen, so small that the red

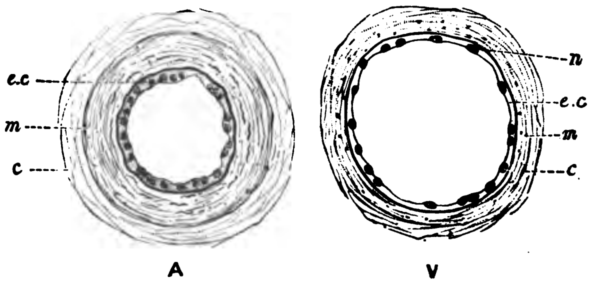


FIG. 47. — An artery and corresponding vein cut across.

A, artery; V, vein; *e.c*, endothelial cells; *m*, muscular coat; *c*, connective tissue coat; *n*, nuclei of endothelial cells.

corpuscles are squeezed out of shape as they are being forced through them. This gives rise to a large amount of friction. The friction of the blood in passing through the capillaries and small arteries is the resistance which the left ventricle has to overcome. The aorta and the other arteries, the capillaries and the veins, are always full of blood, for there is never any space in them unfilled with blood. If you take a piece of soft rubber-tubing, open at both ends, and put it in a basin of water, the tubing will become full of water. If, now, you tie one end of the tubing you can, by means of a syringe at the other end, pump still more water into the tubing, distending it in so doing. You could do the same with a piece of artery. Now during life the aorta and the arteries are naturally more than full, they are always distended; their elastic walls are stretched, so that they are holding more blood than is required just to fill them. The pressure of the extra quantity of blood on the walls is called the **blood pressure.** The distension of the elastic walls exerts an equal pressure on the blood in the arteries, and this presses some of the extra blood out of them into the capillaries. The arteries are constantly trying to get rid of the extra amount of blood by the recoil of their elastic walls on the blood, the elastic walls tending to return to their undistended state. During life just as much blood as is being pressed on through the capillaries is being thrown into the aorta by the beat of the heart. So that during life a distension is always kept up, and the pressure which the walls of the arteries exert on the blood in them always exists. The blood constantly flows out of the arteries into the capillaries, because it is constantly being pressed out of them by the blood pressure. With each beat of the heart a fresh quantity of blood is thrown into the aorta, and the distension is increased a little, that is, the blood pressure is raised a little, and so the blood flows, for the moment, a little faster on through the capillaries, flowing on more slowly again when the beat is over. Hence, although the blood is thrown into the aorta at intervals by the beat of the heart, it flows out of the arteries continuously, being quickened only in its flow by each beat. The blood pressure is greatest at the beginning of the aorta, where the distension is being kept up by the beats of the heart, and gradually diminishes along the whole vascular system round to the heart again. It presses the blood on along the arteries, through the capillaries, and along the veins. In the capillaries there is, owing to the great friction of the minute passages, a strong resistance to the flow of blood, so that a great pressure in the arteries is needed to send the blood on through the capillaries, and a great deal of this is used up in doing so, so that the pressure in the veins on the far side of the capillaries is much less than the pressure in the arteries on the near side of the capillaries, though enough is left to force the blood on through the veins. In the veins, the channels being wider, the resistance is less, and gets less and less as the veins get wider and wider towards the heart. Hence the pressure is greatest in the arteries, less in the capillaries, and least of all in the veins. It is the muscular contraction of the heart which, by getting up the pressure in the vessels, the blood pressure, drives the blood round the whole vascular system back to the heart again. The arteries, as we have seen, have muscular tissue in their walls, but this does nothing to help the blood onward. We shall see that the muscular tissue of the arteries has its uses, but so far as conducting the blood onward is concerned, the arteries simply act as elastic tubes, merely pressing on the blood in them because they are kept over-distended by the blood forced into the aorta by the heart.

The Pulse. — Each fresh quantity of blood forced into the aorta produces a sudden extra distension of the aorta. This extra distension runs quickly over the walls of the whole arterial system, so as to give all the arteries a little extra distension. This extra distension, travelling rapidly along the walls of the arteries, is called the pulse. The pulse may be felt in any artery near the surface of the body; it is very distinct in the artery at the wrist. This travelling of the distension is quite a different thing from the flow of the blood itself. The pulse travels over the arterial walls at the rate of 30 feet per second, going at about the same speed in all the arteries, and hence takes only $\frac{1}{10}$th of a second to travel from the beginning of the aorta to the wrist, while the blood itself travels along much more slowly, requiring about five seconds to reach the wrist. As the pulse runs over the arteries from the aorta the amount of extra distension it causes diminishes continually until in the smallest arteries the effect it produces is small, and, moreover, is distributed over an enormous number of vessels, and in the capillaries the pulse is lost; hence no pulse is perceptible in the veins beyond them. When an artery is cut the blood is thrown out in jerks corresponding to the pulse, and also flows out between the jerks, because the arteries are kept over full, and the blood is pressed out by their elastic walls. When a vein is cut the blood flows out steadily and without jerks, being merely pressed out by more blood coming on through the capillaries.

Velocity of the Blood. — The same quantity of blood goes along the aorta in a second as goes through all its capillaries put together in a second, and as goes along the inferior and superior vena cava together in a second. All the capillaries put together hold a great deal more blood than the aorta, because the bore of all the capillaries put together forms an area very much greater than that of the bore of the aorta. But the same quantity of blood passes along the bore of the aorta in a second as passes through the very much wider bed formed by all the capillaries in a second, and in order to do this the blood rushes along the aorta much faster than it does along the capillaries. For a like reason when a river opens into a lake the velocity of the stream greatly falls in the lake, but increases again in the river leading out of the lake, the same quantity of water passing through the lake as rushes along the river in a given time. The velocity of the blood, then, is greatest in the aorta, less in the smaller arteries, least in the capillaries, and increases again in the veins. In the venæ cavæ close to the heart it is less than in the aorta, because the bore of these veins taken together is greater than that of the aorta. The velocity of blood in the aorta is about 15 inches per second, in the capillaries probably less than $\frac{1}{20}$th of an inch per second, and in the inferior vena cava about half what it is in the aorta.

The Valves of Veins

Exercise the arm for a few minutes to increase the circulation in it; the veins on the front of the forearm will then be prominent. The veins, looked at through the skin, appear bluish in colour, but the blood in them is dark reddish-purple. With the finger stroke one or other of the veins upwards towards the shoulder. You will find that you can press much of the blood out of it. Now stroke the vein downwards towards the hand; you cannot press the blood out of it, and the vein swells up and distends, the swelling being greatest at one or two places along the vein, thus forming "knots." These knots mark the position of valves which prevent the return of the blood towards the hand. The veins are freely connected with one another, so that when two or three veins are compressed, the blood passes up from the limb by other vessels, especially by those deeper in the arm.

Many veins, especially those of the limbs, have valves placed frequently along their course. A valve is formed by a semilunar fold of the inner layer of the wall of the vein, which projects into the vessel, and is directed towards the heart: it forms a pocket like the pockets of the semilunar valves of the heart. Sometimes there is only one such fold, sometimes there are two or even three such folds at the same level. The blood

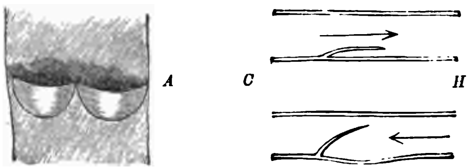


FIG. 48. — Diagram of the valves of veins.

A, a vein laid open to show pouch-shaped valves; *C*, capillary side; and *H*, heart side of a vein. The arrow showing the direction of the blood, in the upper figure towards the heart, in the lower towards the capillaries.

can pass freely through the valve towards the heart, but any pressure on the vein above, or weight of blood in it, only closes the valve so that the blood cannot return towards the capillaries.

The pulmonary vein and the inferior vena cava and the superior vena cava have no valves, nor has the portal vein itself, although the smaller veins of the portal system are well supplied with them. No artery has valves; the semilunar valves at the beginning of the aorta and pulmonary artery belong to the heart.

Regulation of the Circulation

Regulation of the Heart. — We have seen that the skeletal muscles are supplied with nerves, and that when a muscle contracts, it is because an impulse from the spinal cord or brain has reached it along its motor nerve. The heart is also supplied with nerves, but there is this great difference, namely, that the heart can go on beating without receiving impulses along its nerves. When the heart of a frog is cut out of the body it will go on beating for many hours if it is not allowed to get dry. It is the property of the muscle of the heart to go on contracting and relaxing so long as it is alive and not interfered with.

The nerves going to the heart do carry impulses from the brain to the heart, but these are only to regulate the strength and frequency of the beat, not to originate it. When work is being done, the muscles require more blood to bring them more oxygen, and to take away more waste products, and, in order to meet this, the heart beats stronger and faster. This the heart does in accordance with influences which are brought to bear on it through the nerves going to it. Or again, a man may faint from a "blow in the stomach," or from severe mental or bodily pain. This is caused by a sudden weakening or even stopping of the heart, and is brought about by impulses reaching the heart from the brain along one of the nerves going to the heart.

The lower part of the brain, where it becomes continuous with the spinal cord, is called the spinal bulb or medulla oblongata (see chapter on the Nervous System). This is the region of the brain which regulates the heart. From the spinal bulb several nerves are given off on each side, and one of these is called the **vagus** nerve. It runs down the neck to the thorax and abdomen, giving branches to the heart, lungs, and stomach. Impulses of sufficient strength sent along the vagus nerves to the heart cause it almost at once to stop beating, its muscular fibres relax, and then, instead of contracting again, remain relaxed, so that the heart becomes dilated with blood, and remains still and motionless. After a short time, which is generally measured only by seconds, the heart commences to beat again, the beats being as strong as, and, indeed, often at first stronger than before. If the impulses reaching the heart are weak ones only, the effect is, not to stop the heart, but to diminish the rate of beat, and usually at the same time to make each beat weaker. It is by gentle impulses passing down the vagus nerves from the spinal bulb that the heart's beat is chiefly regulated, and, indeed, in many animals such impulses are almost always passing, and so restraining the heart. When such an animal requires a more active circulation, as when it is running, these impulses for the time cease, and in consequence the heart, with the restraining influence removed, beats more quickly and more strongly.

There are also other nerves passing to the heart from the spinal cord, impulses reaching the heart along which cause a quickening and strengthening of the beat. These impulses are also originated in the spinal bulb, whence they are sent down the spinal cord and then out along the nerves mentioned to the heart. Thus the need of the body for a more active or less active blood supply is regulated by a part of the spinal bulb.

Regulation of the Blood-Vessels. — When the heart's beat is quickened all parts of the body get more blood than before; when it is slowed all parts get less. Quickening of the heart's beat cannot give more blood to one organ without giving more to all other organs. But it constantly happens that some organs are doing much more work and require more blood when other organs are doing but little and require less. When digestion is going on the stomach and intestines require more blood, when muscular work is being done the muscles require more, when brain work, such as thinking, is being done the brain requires more blood, and so on. This is brought about by a regulation of the blood supply carried out in each organ or tissue. If the blood-vessels of an organ get narrower, the resistance to the passage of blood is increased, and less blood goes through them, more going through the unchanged vessels of other organs. If the blood-vessels of an organ widen, they offer less resistance to the passage of the blood, and more blood goes through them, less going through the unchanged blood-vessels of other organs. The small blood-vessels can in this way change their bore or calibre, and thus the blood supply to an organ is diminished or increased. These changes are called the **constriction**, narrowing, and the **dilation**, widening, of a vessel. These terms are not to be confused with the contraction and relaxation of a muscle, or with the elastic expansion and elastic recoil of an artery due to the pulse.

How are the constriction and the dilation of a vessel brought about? The smaller arteries consist, as we have seen, of an endothelium with plain muscular fibres wrapped round it. When these plain muscular fibres contract, as they become shorter they must of necessity grip the vessel, making its bore smaller, and so the vessel is constricted; when they again relax the vessel dilates. The layer of plain muscular fibres of the small blood-vessels can in this way regulate the supply of blood to an organ. The vessels are supplied with nerves, which are the motor nerves for these muscular fibres, corresponding to the motor nerves for skeletal muscle fibres; they are called **vaso-motor nerves.**

The plain muscular fibres of the vessels contract when they receive impulses along these nerves, and they relax again when these impulses cease. The nerve fibres which supply the blood-vessels can be traced from the spinal cord, but it is in the spinal bulb that the impulses governing the blood-vessels are generated, and these pass down the spinal cord and then out by several nerves to the small arteries of the body. The part of the spinal bulb which in this way regulates the calibre of the blood-vessels is called the **vaso-motor centre.** The vaso-motor centre constantly sends out impulses so as to keep the muscle fibres of the small arteries naturally a little contracted, and consequently the vessels are kept in a state of slight constriction. The vaso-motor centre keeps a "rein" on the arteries, holding them in a condition of "tone" as it is called. When an organ requires an increase of blood supply, some influence, which varies in different cases, is brought to bear on the vaso-motor centre, which leads to a cessation of the impulses going out to the small arteries of the particular organ, and in consequence the muscle fibres relax and so the small arteries of the organ dilate.

On the other hand, a decrease in blood supply is brought about by more powerful impulses being sent to the muscle fibres of certain vessels, so that they contract strongly, and as a consequence the vessels are much constricted.

Blushing is caused by a dilation of the small arteries of the face. This is brought about by the influence of some emotion such as that of shame on the vaso-motor centre, leading to the withdrawal of the impulses usually passing out to the vessels of the face. Sudden **pallor,** due to fear, is brought about in a similar way, by an increase of the tonic constriction of the small arteries of the face. The commonest cause of sudden pallor, however, is a weakening of the heart, as occurs in fainting.

If the ear is gently rubbed for a few moments, it will become very red. This is due to a dilation of the blood-vessels of the ear, and consequently a large supply of blood to the ear, and this may be brought about by the direct action of the handling on the vessels themselves without the intervention of the central nervous system. The blood-vessels of many organs can thus be locally influenced by various agencies.

There are thus three ways in which the blood supply may be regulated: —

1. Alteration in the heart's beat, leading to a change affecting all parts of the body.
2. By the action of the vaso-motor nervous impulses on the small vessels of particular parts, so as to lead to a change of their calibre.
3. By direct action on the muscle fibres of the small vessels, leading to a dilation of the vessels.

The Lymphatic Circulation

The blood circulates in a system of tubes, the smallest of which, the capillaries, by their close meshwork in the tissues, bring it very close to the individual cells. Still the blood is confined to the tubes. The walls of the blood capillaries are, as we have seen, exceedingly thin, being formed of one layer of flattened cells joined edge to edge. Part of the plasma of the blood passes through the thin walls of the capillaries, and so brings the nutritive material actually to the cells. This fluid, which exudes from the blood-vessels and bathes, as it were, the actual tissues, is called the lymph.

Lymph. — Lymph is a colourless fluid, like blood plasma in composition, that is, consists of water containing proteids, salts, and other substances in solution, but in rather less quantity. When shed it clots like blood plasma. The lymph contains colourless corpuscles like those of the blood, but no red ones.

Lymphatic Vessels. — The lymph lies in spaces which exist between the cells of the tissues, and these spaces are drained by a network of delicate vessels, called lymphatic vessels, which gradually unite with one another, forming a few main lymphatic vessels by which the lymph is carried away from the tissue or organ. The walls of a lymphatic vessel are very delicate and thin, and are formed of a single layer of flattened cells joined edge to edge, the larger ones having in addition a little fine connective tissue and some plain muscular fibres outside this, but the walls are nevertheless transparent. The lymphatic vessels of one organ or tissue join those of others; thus the lymphatic vessels of the leg are formed by the union of those from the muscles and other tissues of the limb. These vessels can be traced up the limb into the abdomen to a main lymphatic vessel lying in the trunk just in front of the vertebræ. This vessel is called the **thoracic duct.** It lies in the thorax on the front of the dorsal vertebræ, passes through the diaphragm, and extends down the abdomen to the level of the lumbar vertebræ, where the lymphatics from the legs and lower part of the trunk open into it. The lymphatics from the intestine and the other abdominal organs also open into it, so that the lower end of the thoracic duct is larger than the rest of it, and is called the **receptaculum chyli.** As the thoracic duct passes up the thorax the lymphatic vessels from the thoracic organs join it, and higher still it receives those from the left arm and from the left side of the head and neck. The upper end of the thoracic duct, which is only a quarter of an inch in diameter, turns towards the left side, and at the root of the neck opens into the large vein — the jugular vein — coming down the left side of the neck just as the vein joins with the left subclavian vein, the main vein of the left arm. The vein formed by the union of these two veins opens into the superior vena cava. The lymphatics of the right arm and right side of the neck are collected into a small duct which opens into the right jugular vein. Thus the lymph, which exudes from the blood capillaries, is returned by the lymphatic vessels and the thoracic duct to the blood again.

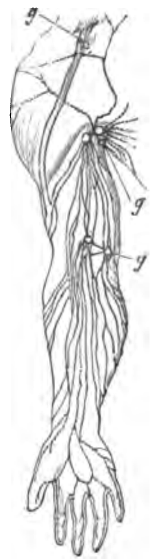


FIG. 49. — The lymphatic vessels of the front of the right arm. *g*, lymphatic glands.

Along the lymphatic vessels and the thoracic duct are numerous valves, formed like the valves in veins, which allow the flow of the lymph in the right direction only. A valve guards the opening of the duct into the jugular vein. The lymph flows along because the pressure where it is constantly being formed from the capillaries is greater than is the pressure in the great veins where it is poured into the blood, and also because any movement of the body by pressure on the tissues drives the lymph past the valves which prevent its return.

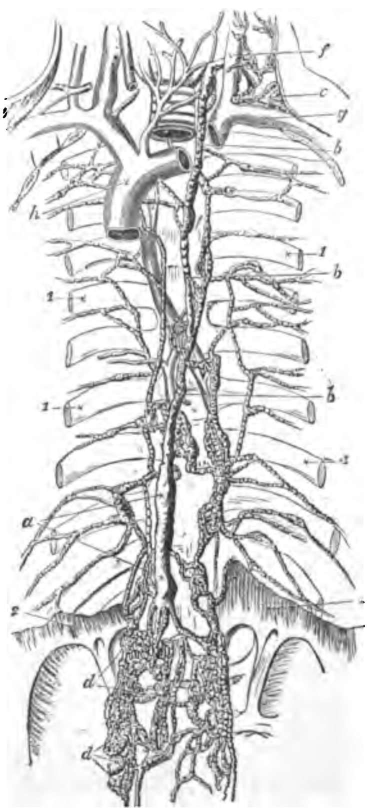


FIG. 50. — The thoracic duct.

1, part of ribs; *a*, receptaculum chyli; *b*, trunk of thoracic duct, opening at *c* into junction of left jugular (*f*) and left subclavian (*g*) veins. The connection of these veins with the superior vena cava (*h*) has been cut across to show the thoracic duct behind it; *d*, lymphatic glands in the lumbar regions.

Lymphatic Glands.— Along the course of the lymphatics small solid bodies are met here and there which vary in size, some of the largest being an inch or more in length, and are often bean-shaped. Lymphatics open into them on one side and leave them on the other. These are called lymphatic glands. Each consists of a meshwork of fine connective tissue, holding in its meshes a large number of colourless corpuscles closely packed together. The colourless corpuscles or leucocytes as they are called, are smaller than the colourless corpuscles of the blood; in fact, they are young colourless corpuscles which are being formed by the division of corpuscles into two, and then each of these two into two more, and so on. The lymph flows through this meshwork, and some of the leucocytes are carried away in the stream. In this way the lymph brings new colourless corpuscles to the blood. All the colourless corpuscles of the blood arise in this way from lymphatic glands or from similar tissue elsewhere.

In addition to the plasma of the blood which passes out of the capillaries to form lymph, some colourless corpuscles pass out, between the endothelial cells, with it, so that there are colourless corpuscles throughout the lymphatic system.

From the blood in the capillaries, and by means of the lymph, the tissues obtain all they require for their life. What those substances are we shall learn later, but one of them is oxygen. Similarly the tissues return their waste products to the blood, and one of these is carbonic acid. The supply of oxygen and the withdrawal of carbonic acid is carried out by respiration, which we will now consider.

CHAPTER XI

RESPIRATION

Arterial and Venous Blood. — Get some blood at a butcher's and defibrinate it. Put some of the blood into two bottles. Pass carbonic acid gas into one bottle, shaking at the same time. Shake the other with air, and after a few minutes notice the colour of the blood in each. The blood shaken with air is scarlet as before, or even brighter; the blood shaken with carbonic acid is dark reddish-purple. Take some of the dark purple blood out and shake it up with air — it becomes scarlet again. The colour of the blood is entirely due to the hæmoglobin of the red corpuscles, and hæmoglobin is reddish-purple in colour. When blood is exposed to air the hæmoglobin takes up oxygen from the air and becomes oxyhæmoglobin, and this is scarlet in colour. When blood is exposed to carbonic acid gas, or to air containing but little oxygen, the oxyhæmoglobin parts with oxygen and becomes hæmoglobin again. Thus hæmoglobin has the power of taking up oxygen into loose chemical combination, and of readily giving it up again.

The blood in the left chambers of the heart and in the arteries of the general circulation is bright scarlet in colour. Bright scarlet blood is therefore called arterial blood. The blood in the veins of the general circulation and in the right chambers of the heart is dark reddish-purple. Reddish-purple blood is therefore called venous blood. When venous blood is shed it comes in contact with the air, and the hæmoglobin in it which is not already united with oxygen takes up oxygen from the air and becomes oxyhæmoglobin, so that the blood soon becomes brighter in colour and nearly as bright as arterial blood. If a large clot of blood be cut into and examined, it is found that the clot is brighter red near the surface than it is deeper in. When the clot was first formed it was bright red throughout, but, on standing, the deeper parts of the clot become dark, because certain substances, occurring in minute quantity in the blood, are slowly oxidised by the oxygen which they take from the oxyhæmoglobin, and this consequently turns to the dark-coloured hæmoglobin; substances which thus take oxygen from another substance are called reducing substances. Near the surface of the clot the oxyhæmoglobin, when it gives up oxygen to the reducing substances can get a fresh supply from the air, and so remains the bright-coloured oxyhæmoglobin.

Diffusion. — If, instead of shaking up the defibrinated blood with carbonic acid gas, it be put in a bladder and hung up in the gas, the same change will take place; and if it is hung up in air in which the quantity of oxygen and of carbonic acid can be varied, the colour can be changed from one to the other as often as wished. The gases pass through the bladder membrane by what is called diffusion, just as they would if a bladder containing oxygen were hung up in carbonic acid gas. If this were done you would find that, after a short time, the gases inside and outside the bladder would be the same, each containing carbonic acid gas and oxygen in the same proportion. The gases diffuse through the membrane until the pressure of each gas inside and outside the bladder is the same.

The Change of Arterial Blood to Venous Blood. — The change of arterial blood to venous blood takes place as it passes through the capillaries of the tissues.

The tissues are constantly using up oxygen for their life, so that there is no, or only a little, free or loosely-combined oxygen in them. The blood in the capillaries, on the other hand, contains much oxygen held loosely by the hæmoglobin. Some of this is given off and passes through the capillary walls into the lymph, and thence is taken up by the tissues. Some of the oxyhæmoglobin is thus reduced to hæmoglobin again. The longer the blood stays in the capillaries the more of its oxygen it gives up, but it rarely happens that it stays long enough to give up all its loosely-combined oxygen.

The tissues are constantly forming carbonic acid by their life, so that there is much free or loosely-combined carbonic acid in them. The blood in the capillaries, on the other hand, though it contains carbonic acid, partly in solution in the plasma and partly in loose combination with the salts and other substances in the blood, contains much less than do the tissues. Some of the carbonic acid of the tissues passes into the blood, and if the blood stays long enough it will go on passing into the blood until the blood is just as much loaded with carbonic acid as are the tissues. The oxygen passes from the blood and the carbonic acid passes to the blood by the process of diffusion which tends to make the pressure of each gas the same in the blood and in the tissues.

The Change of Venous Blood to Arterial Blood.—The change of venous blood to arterial blood takes place as the blood passes through the capillaries of the lungs. The venous blood is driven by the heart along the pulmonary artery through the capillaries of the lungs, and having there lost carbonic acid and gained oxygen, passes as arterial blood along the pulmonary vein to the heart again.

The air in the lungs, as we shall see, is separated from the capillaries of the lungs by a very thin membrane only, through which gases can readily pass. The venous blood brought to the lungs contains more carbonic acid than the air in the lungs, and some of it therefore diffuses through into the air. If the same air stayed long enough in the lungs all the venous blood which was sent through them would give up some of its carbonic acid to it, until the air in the lungs was as much loaded with carbonic acid as the blood in the capillaries of the lungs, and then the process would stop. The air in the lungs is, however, to a great extent renewed at each breath, so that the air does not leave the lungs so heavily laden with carbonic acid as is the venous blood, while, on the other hand, the frequent renewal of the air in the lungs makes the giving up of carbonic acid by the venous blood quicker, because the greater the difference between the amounts they each contain the faster is the diffusion from one to the other.

The venous blood brought to the lungs contains much hæmoglobin which is not combined with oxygen, while the air in the lungs contains much free oxygen. Some of this diffuses into the blood and is taken up by the hæmoglobin, so that this is all converted again into oxyhæmoglobin.

In this way the air in the lungs gains carbonic acid and loses oxygen.

Changes in the Air. — Put some clear lime water into a bottle and by means of a tube blow the air you expire through it. In a short time the lime water becomes "milky." This is because the lime takes up carbonic acid from the expired air, and carbonate of lime is formed as a white precipitate. If you suck ordinary air through lime water, no milkiness, or only a very little, is produced. This shows that air that has been taken into the lungs has gained a quantity of carbonic acid. If two bottles containing lime water are arranged as in Fig. 51, breathing can be carried on naturally through the tube C, the inspired air coming in through A, and the expired air going out through B. A remains clear, B becomes milky.

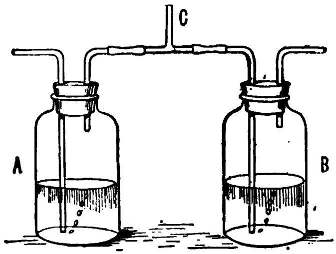


FIG. 51.

Ordinary atmospheric air breathed into the lungs contains in 100 volumes about —

Nitrogen	79.0 volumes
Oxygen	20.9 "
Carbonic acid gas . .	.04 "

and a variable amount of water in the form of aqueous vapour. The air expired from the lungs contains in 100 volumes about —

Nitrogen	79 volumes
Oxygen	16 "
Carbonic acid gas . .	4 "

There is therefore a loss of 4 or nearly 5 per cent of oxygen and a gain of 4 per cent of carbonic acid gas. The temperature of the atmospheric air varies very much, but the expired air is at, or nearly at, the temperature of the body (98° F.), whatever that of the air inspired is. The expired air is always saturated with aqueous vapour. When the temperature of the air expired suddenly falls, as it does on a frosty morning, some of the aqueous vapour in it condenses to a cloud, or, if breathed on to a cold surface such as a window pane, to minute particles of water. The expired air also contains organic substances in very small amount; the importance of these is that they are injurious if breathed in again. The amount of nitrogen is usually unchanged, but sometimes there is a very little more, sometimes a little less, in the expired air than in the inspired air. Thus the body by the lungs gains oxygen, and loses carbonic acid and water. When oxygen unites with carbon the carbonic acid formed occupies the same volume as the oxygen consumed, so that if all the oxygen taken in by the lungs was used in this way, the amount of carbonic acid formed would be exactly equal to it. The volume of carbonic acid, however, given off by the lungs is always a little less than the oxygen taken in. This shows that the oxygen is used for other purposes than merely uniting with carbon. The oxygen is taken up by the tissues, and as they break down most of it unites with the carbon of the tissues, but some of the oxygen unites with the hydrogen of the tissues to form water, and some of the water so formed leaves the body by the lungs as aqueous vapour. A very small amount of the oxygen unites with other elements, such as sulphur.

The Respiratory Organs

The Upper Air Passages.—On its way to the lungs the air passes through the mouth or nose, the pharynx, the larynx, and the trachea. The sides of the cavity of the mouth are formed by the cheeks, the floor by the tongue, and the roof by the **palate**, the partition separating the cavity of the mouth from that of the nose. The front of the palate is hard (the hard palate) from the presence of a plate of bone; the hinder part is soft (the soft palate) and consists of a thin sheet of muscle, covered like the rest of the lining of the mouth by a layer of tissue called mucous membrane. The soft palate, which carries in the centre a prolongation, the **uvula**, meets the side walls of the mouth at the pillars of the **fauces**, as they are called, between which the **tonsils** are placed. The soft palate hangs down like a curtain, and when it is fully depressed separates the mouth from the pharynx.

The nose contains a cavity on each side separated by a central partition. The cavity on each side is partly divided into chambers by three delicate scroll-like bones, which project from the sides. The cavities open in front by the nostrils or **anterior nares** to the exterior, and behind by the **posterior nares** into the pharynx above the soft palate. The soft palate can be drawn up over the posterior nares, so as to shut off the cavity of the nose from the pharynx. In quiet respiration the air is breathed through the nostrils; the ingoing air is thus warmed by, and gains moisture from, the walls of the nasal chambers.

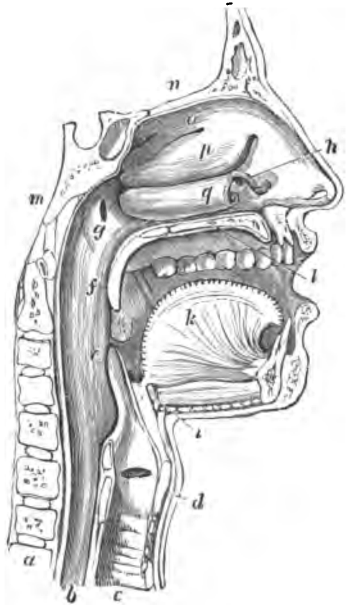


FIG. 52.—The upper air passages. Vertical section.

a, vertebral column; *b*, œsophagus; *c*, trachea; *d*, larynx; *e*, epiglottis; *f*, soft palate and uvula; *g*, opening of left Eustachian tube; *h*, opening of left lachrymal duct; *i*, hyoid bone; *k*, tongue; *l*, hard palate; *m*, *n*, base of skull; *o*, *p*, *q*, the three scroll-like or turbinal bones.

The pharynx is a wide funnel-shaped cavity, 4 inches long, the walls of which consist of sheets of striated muscle lined by mucous membrane. At its lower end it opens behind into the œsophagus, and in front into the larynx, a chamber with cartilaginous walls in which the voice is produced, and which opens below into the trachea. The opening into the larynx is slit-like, and is the aperture of what is called the **glottis**. Immediately above the glottis is a cartilaginous lid-like structure, called the **epiglottis**, which is drawn down backwards over the glottis when food is being swallowed, and so the food is prevented from passing into the larynx.

Structure of the Trachea and Lungs.—Obtain from a butcher the lungs and trachea of a sheep. The trachea is a tube which left to itself remains widely open and indeed cannot be closed by pressure. It is kept open by bands of cartilage in its wall. These bands form rings of cartilage which, however, can be felt to be incomplete down one side of the trachea. This side is the back of the trachea, and in the body was in contact with the œsophagus. Cut open the trachea longitudinally with scissors. Notice that the internal surface of the trachea is smooth, the cartilages lying in the thickness of the wall. Each cartilage is a flattened band, the ends of which are connected together along the back of the trachea by plain muscular tissue. The external coat of the trachea consists of connective tissue containing a little fat. The internal coat of the trachea is a mucous membrane, consisting of an internal epithelium resting on a layer of connective tissue. The epithelium consists of cells, the surface layer of which are columnar and bear a large number of short hair-like processes. These processes are called **cilia**. The cilia are during life constantly in a wavy motion, each bending sharply and then slowly straightening again. Since all those in one area act together, they drive any fluid on them in the direction in which they bend, and this is, in the trachea, outwards towards the mouth. Ciliated cells also line the larynx and parts of the chambers of the nose.

Close to the lungs the trachea divides into two tubes, the **bronchi**, one going to each lung. Cut open one of the two bronchi lengthways. Notice that it gives off branches and gradually divides into a large number of smaller tubes, the **bronchial tubes**. The bronchi and bronchial tubes have a structure similar to that of the trachea, having a ciliated epithelium and containing also cartilage in their walls, but the cartilage bands are even less complete than in the trachea, and as the bronchi become smaller, become less regular until, in the smaller bronchial tubes, only scattered pieces of cartilage are present and in the smallest tubes none at all. Go on cutting open, with fine scissors, the bronchial tubes as far as you can into the substance of the lung. As they divide into smaller tubes they soon become too small to be traced in this way. Microscopical examination shows that each minute bronchial tube finally divides into a cluster of short, blind, somewhat dilated branches. These dilated terminations of each bronchial tube are called

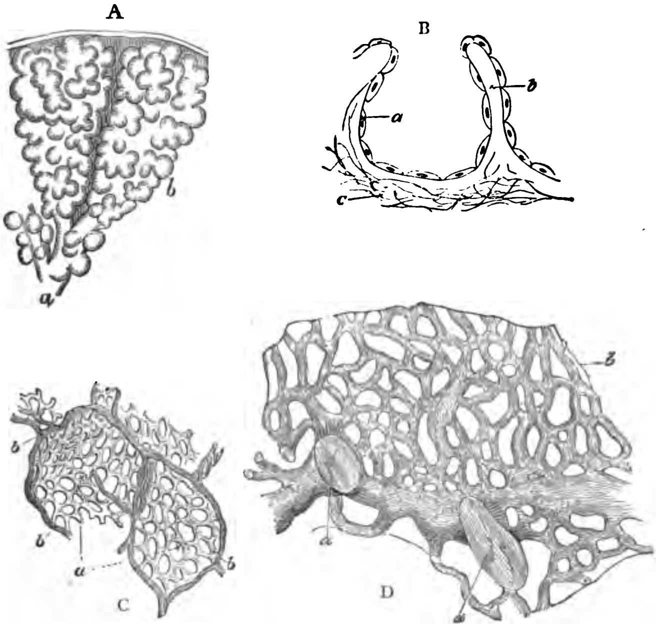


FIG. 53. — Diagrams to show the structure of the lungs.

A. — *a*, an ultimate bronchial tube opening into two infundibula, each consisting of a number of alveolar chambers, *b*.

B. — The wall of an alveolar chamber. *a*, the epithelium; *b*, partition between two alveoli, in which the capillaries lie; *c*, fibres of elastic tissue.

C. — The blood-vessels of two alveoli. *a*, networks of capillaries; *b*, small arteries and veins.

D. — The same very highly magnified.

infundibula. The wall of each infundibulum is folded inwards, partly dividing the dilated cavity into a number of chambers. Each of these chambers is called an **alveolus**.

Each infundibulum consists of a cluster of alveoli, into all of which the fine bronchial tube conducts air. The lung is thus made up of the closed dilated ends of an enormous number of fine bronchial tubes, which are connected together by a little fine connective tissue, the whole being covered by a transparent elastic membrane, the visceral pleura. In the body this membrane, fragments of which may be stripped off the surface of the lung, is continuous at the root of the lung with the parietal pleura, lining that half of the cavity of the thorax.

The walls of the alveoli consist of fine elastic connective tissue, lined internally by a layer of flattened cells joined edge to edge. Lying in the fine connective tissue, just underneath the layer of flattened cells, as a close network of blood capillaries, so that the capillaries are separated from the air in the alveoli by this thin layer alone. The branches from the pulmonary arteries run near the bronchial tubes and break up into the capillaries over the walls of the alveoli, the blood being collected again by veins running back to the root of the lung, and so to the heart.

Tie a tube into the bronchus of the other lung and blow air into it. The lung can thus readily be expanded to twice its previous size, but when left to itself at once shrinks again, driving the air out. By blowing air in, the alveoli are dilated and their walls are put on the stretch, and when the blowing in is stopped the elastic recoil of the walls drives the air out again. Some air always remains in the lungs; if a bit of the lung is thrown into water it floats because it contains air.

The Natural Condition of the Lungs.—When the lungs are in the unopened thorax there is no air in the thorax round the lungs, the air has no access to the outside of the lungs, and the stiff walls of the thorax ward off the pressure of the atmosphere from the outside of the lungs, hence the pressure of the atmosphere, exerted through the air in the bronchial tubes and alveoli, keeps the lungs distended so that each lung fills up completely each lateral half of the thorax. The pressure of the atmosphere keeps the lungs as much distended with air as the size of the thorax will allow. But when the thorax is opened, as by a wound in the chest, air enters the thorax, and the pressure of the atmosphere is then exerted on the outside also of the lungs, so that the pressure inside and outside the alveoli is equal; there is therefore no force to keep them distended. The lungs at once shrink to less than half their natural size, and the elastic walls of the alveoli are no longer on the stretch, as they constantly are before the thorax is opened.

When the thoracic cavity is increased in size the atmospheric pressure can distend the lungs still more, and so more air goes into the lungs; but however much the thoracic cavity is increased, each lung always fills its corresponding half. When the thoracic cavity is decreased in size the lungs have less room, and so some of the air is driven out of them, so that they are less distended than before. The size of the lungs depends therefore on the size of the thorax. Thus more air will go into the lungs if the thorax is increased in size, because the lungs can then be further distended by the pressure of the atmosphere. It is the pressure of the atmosphere that drives the air into the lungs when the thorax is being increased in size. The pressure of the air in the lungs has no power of itself to increase the size of the thorax, because the atmosphere is pressing with equal force on the outside of the thorax as well. Thus in order that air may be drawn into the lungs, the thorax has to be increased in size by some force of the living body. The thorax is increased in size by the flattening of the arch of the diaphragm and by the elevation of the ribs, both being brought about by muscular contraction. Drawing air into the lungs is called inspiration, forcing air out of the lungs is called expiration, and the two together constitute respiration.

The Respiratory Movements of the Walls of the Chest

The Action of the Diaphragm — Inspiration. — The diaphragm, which separates the thorax from the abdomen, is arched upwards, so that it is convex to the thorax. It is covered by peritoneum below and by pleura above. The centre of the diaphragm consists of a sheet of tendon, to which bands of striated muscle are attached all round. These muscular bands form the greater part of the diaphragm and make it in reality a muscular partition, tendinous in the centre only. By means of these muscular bands the diaphragm is attached in front to the sternum and to the cartilages of the ribs which meet the lower end of the sternum, at the sides to the lower ribs, and at the back by two particularly strong bands, called the pillars of the diaphragm, to the bodies of the lumbar vertebræ. The muscular portion of the diaphragm, like other muscular tissue, is capable of contraction, and when this takes place the parts to which the diaphragm is attached are not moved, but the muscular portion pulls on the

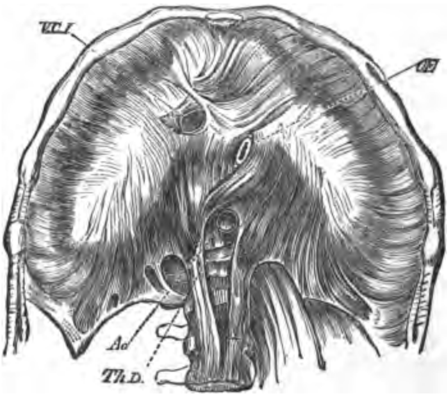


FIG. 54.—The diaphragm viewed from the abdomen.

The central tendinous part is more lightly shaded than the outer muscular part. The following structures passing through the diaphragm are shown cut across:—*Ao*, aorta; *ThD*, thoracic duct; *V.C.I*, inferior vena cava; *Œ*, œsophagus.

central tendinous portion, and drawing this down causes the arch of the diaphragm to become less convex. This increases the thoracic cavity from above downwards.

The Movements of the Ribs and Sternum—Inspiration.—The ribs, sweeping round from the vertebral column behind to the sternum in front, form with the intercostal muscles between them the lateral walls of the chest. The ribs do not proceed horizontally round the wall of the chest, but slope obliquely downwards as they proceed forwards from the back. The first rib forms the smallest arch, and the arch of each increases as we pass downwards to the last of them, the seventh, which meets the sternum. Each rib is articulated, as we have seen, to the vertebral column. These joints allow the ribs to be raised from their natural oblique position to a more horizontal position, that is, an up and down movement of the front ends of the ribs can take place. When the lower ribs with their larger arches are thus raised they come into the position previously occupied by the smaller arches of the ribs above them. This increases the size of the thorax. The vertebral column, ribs, and sternum thus form a cage, the shape of which can be changed by the up and down movement of the ribs on the vertebral column. As the anterior ends of the ribs move upwards they carry the sternum upwards with them; and in moving upwards, as they pass from a slanting position to a more horizontal position, they increase the distance of the sternum from the vertebral column, so that by the upward movement of the ribs on the vertebral column the sternum is raised upwards and thrust forwards. The cavity of the thorax is thereby increased from behind forwards.

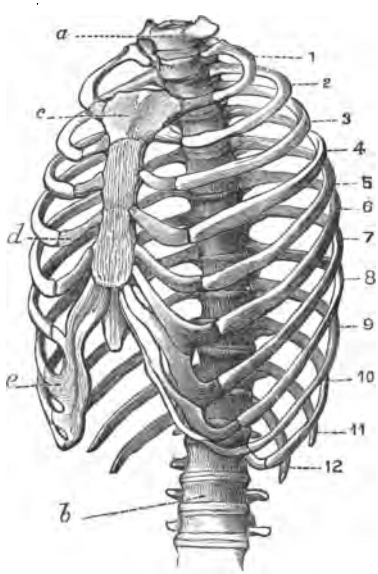


FIG. 55. — The bony walls of the thorax.
a, *b*, vertebral column; 1–12 ribs; *c*, sternum; *d*, costal cartilages; *e*, united cartilages of lower true ribs.

Between the ribs are muscles, the intercostal muscles passing from one rib to the next below it. There are two layers of these muscles between each rib, an external layer and a deeper internal layer. The ribs are raised by the contraction of the **external intercostal muscles**. The fibres of the external intercostal muscles pass from one rib obliquely downwards and forwards to the rib below. When the fibres passing from the first rib to the second rib contract, the second rib is drawn upwards towards the first rib, the first rib being prevented from being drawn downwards by structures above it, and when necessary by the action of the **scalene muscles** which pass from the cervical vertebræ down to the first and second ribs in front. Similarly the external intercostal muscles between the second and third ribs draw the third rib upwards towards the second, and so on for the succeeding ribs. All the external intercostal muscles contract at the same time, and thus all the ribs are raised towards the first, the lower ones moving upwards most. In this way the sternum, especially its lower end, is carried upwards and thrust forwards. Look at the chest of a boy sideways; you will see this movement of the sternum taking place, giving an increase in the size of the chest from behind forwards with each inspiration.

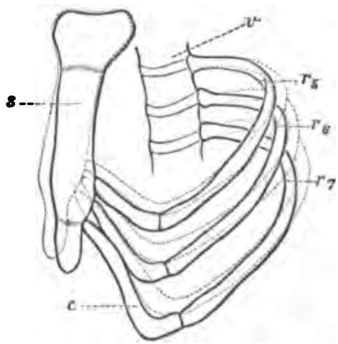


FIG. 56.—Diagram to show the movements of the ribs and sternum in inspiration. *r* 5, *r* 6, *r* 7, 5th, 6th, and 7th ribs; *v*, vertebral column; *s*, sternum; *c*, cartilages. The dotted lines show the position of the ribs and sternum at inspiration.

Look at the chest of a boy from the front; you will see that, with each inspiration, the chest, especially the lower part, increases in width from side to side. This you can distinctly see is caused by the arches of the lower ribs, especially of the seventh, eighth, and ninth, which are united together by their cartilages to form the prominent lower limit of the framework of the chest, moving outwards. For not only do the ribs slant so that their sternal ends are on a lower level than their vertebral ends, but they sag in the middle of their curvature, so that the middle of the arch does not prop out the wall of the chest as much as it would if it had not, as it were, dropped away. When the external intercostal muscles contract this middle part of each rib is especially raised, and so the lateral walls of the chest are thrust out. In this way the chest is increased from side to side.

An inspiration, then, is caused by the contraction of the diaphragm and of the external intercostal muscles at the same time, whereby the chest is increased in size from above downwards, from behind forwards, and from side to side.

Expiration. — An expiration takes place when these muscles relax, the diaphragm returns to its more arched form, and the

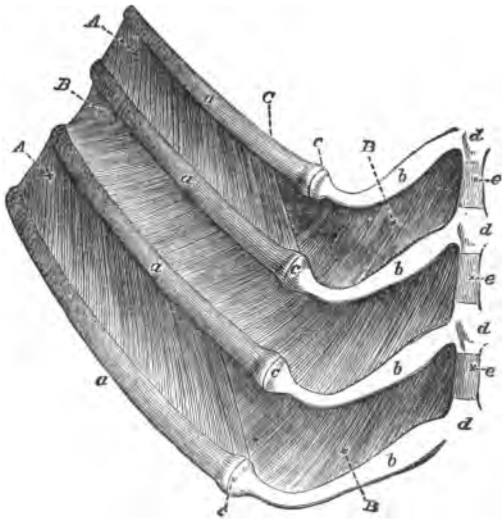


FIG. 57. — Four ribs with intercostal muscles shown.

a, ribs; *b*, cartilages; *c*, junction of ribs with cartilages; *d*, *e*, sternum; *A*, external intercostal muscles; in the middle space this muscle has been removed to show *B*, the intercostal muscle of that space.

ribs and sternum return to their position of rest. While inspiration is taking place, the costal cartilages connecting the ribs to the sternum, as well as other parts of the thoracic walls, being elastic, bend, give or are put on the stretch, and when the muscular effort, which causes the inspiration, ceases, the elasticity leads to a return of the chest walls to their original condition. The position of the ribs, sternum, and diaphragm in inspiration cannot be maintained without muscular effort, so that when this ceases the chest returns to its original size, and the air is driven out of the lungs again. Moreover, the lungs themselves are very elastic and when distended will, as we have seen, return to their original size when the distending force ceases to act. Thus inspiration is brought about by a muscular effort, while expiration is in the main the result of the cessation of that effort, and the passive return to the natural condition is due to the elasticity of the chest walls and of the lungs themselves.

Quiet Respiration.—Quiet respiration is effected by movements of both the diaphragm and of the ribs, but the relative part they play varies much in different animals and in ourselves in the two sexes. In men the diaphragm takes a greater share, that is, diaphragmatic respiration is more evident, while in women the movement of the ribs, that is, costal respiration, is more conspicuous. When a person is quiet and at rest the rate of respiration is about seventeen every minute, but is very variable. An inspiration takes place which is followed at once by an expiration, then there is nearly always a pause, and then another inspiration and expiration occur, and so on.

Laboured Respiration.—When deep inspiration or laboured inspiration, as it is called, occurs, other muscles which can raise the ribs and the sternum contract. These are chiefly the large muscles passing from the upper part of the spine to the upper ribs behind, and those passing from the neck to the sternum in front. Moreover, unlike what happens in quiet expiration, when laboured expiration occurs certain muscles contract to help to drive out the air. The most important of these are the muscular sheets which form the anterior wall of the abdomen, the **abdominal muscles.** When these contract they cause pressure on the abdominal organs, and these press up the arch of the diaphragm still farther into the thorax. The second deeper layer of intercostal muscles, the **internal intercostal muscles,** which pass from each rib obliquely downwards and backwards to the rib below, depress the lower ribs when they contract. These, with other muscles which pass from the lower part of the spine upwards to the lower ribs and can depress them, are the muscles which act when violent expiration takes place; all these muscles cause, when they contract, a diminution in the size of the thorax. If the hand is placed on the abdomen when a cough is made, the muscles of the abdominal wall will be felt to become hard and tense as they suddenly contract and press on the abdominal contents. A **cough** is a strong expiration which suddenly bursts upon the

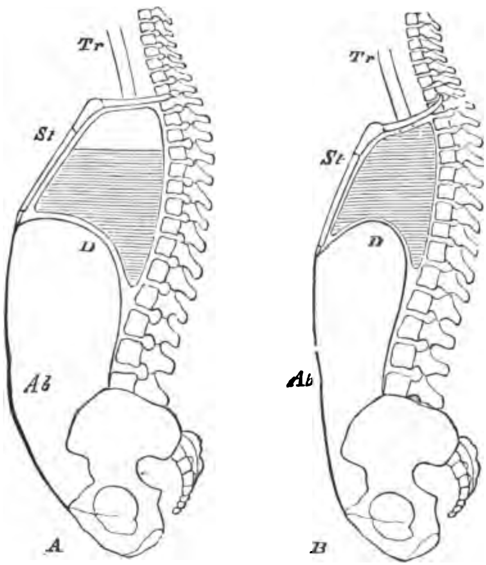


Fig. 58.—Diagram to show the changes in the sternum, diaphragm, and abdominal wall in respiration.

A, inspiration; *B*, expiration; *Tr*, trachea; *St*, sternum; *D*, Diaphragm; *Ab*, abdominal wall. The shaded part is to indicate the stationary air.

closed glottis. The strong expiration is preceded by a deep inspiration. **Sighing** is a deep inspiration, followed by a gentle expiration. **Sneezing** is produced by a sharp expiration, the air being driven out through the nasal passages, the passage from the pharynx to the mouth being closed by the descent of the soft palate towards the back of the tongue and the approximation of the pillars of the fauces.

Quantity of Air respired.—At each inspiration an adult man will take into the lungs 20 to 30 cubic inches of air, and pass it out again at the succeeding expiration. This is called the **tidal** air. By the most powerful expiration from 75 to 100 cubic inches of air may be driven out in addition to the tidal air. This is called the **supplemental** air. What is then left in the lungs, which is about 100 cubic inches, is called the **residual** air. By the deepest inspiration 100 cubic inches of air may be taken in in addition to the tidal air. This is called the **complemental** air. Thus at the end of an ordinary expiration there are about 200 cubic inches of air in the lungs, and this air, which is called the **stationary** air, is only renewed by being mixed with the tidal air in the smaller bronchial tubes. We have seen that the air in the alveoli of the lungs is separated from the blood capillaries by nothing more than a thin layer of flattened cells, and that oxygen diffuses from the air into the blood, and carbonic acid diffuses from the blood into the air; so that it is with the air in the alveoli that the interchange takes place, and the alveolar air in turn interchanges gases with the tidal air by rapid diffusion.

Dependence of Respiration on the Central Nervous System.—The movements leading to inspiration are brought about by the contraction of certain skeletal muscles, and we have seen that the skeletal muscles of the body contract only when they receive nervous impulses along their motor nerves. The motor nerves for the intercostal muscles come from the thoracic region of the spinal cord, and the motor nerves for the diaphragm, of which there are two, one on each side, called the phrenic nerves, come from the cervical region of the spinal cord. If the phrenic nerves are cut, the diaphragm does not contract, because no motor impulses reach it; similarly, the intercostal muscles can be put at rest by dividing their motor nerves. Thus respiration is caused by impulses passing at regular intervals from the central nervous system to the appropriate muscles. The impulses start from the spinal bulb, pass down the spinal cord, and then out along the motor nerves in question. The part of the spinal bulb from which these impulses start is called the **respiratory centre**. If this part is injured respiration stops.

Regulation of Respiration.—The respiratory centre can be influenced so that the impulses it sends out are modified in strength, character, or frequency. Thus if there is anything irritating the trachea or larynx impulses pass from them along the sensory nerves (and the sensory nerves of the trachea and larynx are branches of the vagus nerves) to the spinal bulb, and these impulses so influence the respiratory centre that it sends out powerful impulses to the expiratory muscles, and a cough is the result. Again, a dash of cold water will cause a sudden strong inspiration. This is caused by impulses passing along the sensory nerves of the skin to the central nervous system, and so to the respiratory centre, causing it to send out strong impulses to the inspiratory muscles. When a man is running his respiration is quickened; this is due to the blood of the body containing the large amount of waste products produced by the violent muscular contraction; more oxygen is used up and more carbonic acid is formed. A deficiency of oxygen and an increase of carbonic acid in the blood, together with the presence of other substances formed by muscular contraction, so act, when the blood reaches the spinal bulb, on the respiratory centre as to stimulate it to greater activity, and cause it to send out impulses faster; hence a quicker respiration is the result.

Asphyxia. — If air cannot pass into and out of the lungs, as, for example, when there is something blocking the larynx or trachea, such as some food which has "gone the wrong way," the blood gradually becomes more and more venous, that is, more and more charged with carbonic acid and more and more deficient in oxygen. The first effect of the obstruction is to lead to coughing, violent expiratory efforts, the object of which is to remove the obstruction. This coughing is caused, as we have seen, by the action of sensory impulses brought from the larynx to the respiratory centre. If this does not succeed in removing the obstruction, the blood gradually becomes more and more venous, more and more charged with carbonic acid, and more and more deficient in oxygen. This venous blood acts on the respiratory centre so as to stir it up to increased activity, and it sends out nervous impulses, which cause not only quicker respiration, but much more powerful inspirations, followed by more powerful expirations. Such a condition of respiration is called **dyspnœa.** The demand for oxygen of the brain, especially of the spinal bulb, leads to a fuller flow of blood through the brain. This is brought about by the venous blood acting on the vasomotor centre, which is situated, as we have seen, in the spinal bulb, causing it to send out more powerful constrictor impulses to the small arteries of other parts of the body, especially of the abdominal organs, cutting off much of the blood from those parts, and causing an increase of pressure in the aorta, so that more blood is driven to the brain. As the blood becomes more and more venous, the dyspnœa increases in violence till almost all the muscles in the body are thrown into contraction; that is, **convulsions** occur in the struggle to get fresh air into the lungs. If the obstruction is not removed these soon suddenly cease, exhaustion occurs, the beats of the heart become weaker, the blood pressure falls, and the circulation of the blood becomes feeble. At this stage all or nearly all the oxygen in the blood has been used up, and the blood will be so dark as to justify the expression that the man is "black in the face." The respiratory centre deprived of oxygen then rapidly fails, and after a few feeble respiratory efforts, ceases altogether to send out impulses, and so the breathing stops. When the respiration has ceased, the heart, after a few flickering beats, stops also. Such a death is called a death by asphyxia.

The Loss from the Body by the Lungs.—An adult man breathes in and out $17 \times 30 = 510$ cubic inches of air in one minute, so that he will charge about 500 cubic inches of air to the extent of 4 per cent of CO_2 in one minute. Or, in other words, he breathes out 20 cubic inches of CO_2 in one minute, or 1200 cubic inches in one hour. By actual experiment it is found that the amount of CO_2 a man, when at rest, expires in one hour, may be taken as about 1000 cubic inches. When doing hard work he would expire 2000 to 3000 cubic inches. Of the 24,000 cubic inches of CO_2 which a man, at rest, gives off in twenty-four hours, the oxygen is supplied by the air inspired, but the carbon is derived from the tissues of the body. This amount of CO_2 contains about eight ounces of carbon. The water, expired as aqueous vapour, amounts to about half a pint in twenty-four hours.

Ventilation.—Air which has been breathed till it contains more than .2 per cent of CO_2 is injurious, not so much on account of the CO_2 present, but on account of the poisonous nature of the organic matter which is given off by the lungs. In one hour a man, by quiet respiration, will vitiate 3000 cubic feet of air to this extent. Thus the air in a good-sized room, 18 feet by 18 feet and 10 feet high, containing 3240 cubic feet, should be totally renewed every hour. Air is also vitiated by lights in the room; a cubic foot of coal-gas produces when burnt 2 cubic feet of CO_2, besides some sulphur dioxide and other substances. One gas-burner consuming 3 cubic feet per hour of gas would vitiate 3000 cubic feet of air to the extent of .2 per cent of CO_2 in an hour. It is estimated that in the crowded rooms in many small houses in England there is often less than 500 cubic feet of air space for each person. The air in such a room should be completely changed six times in an hour to keep the air pure enough to be breathed without injurious effect.

The lungs, then, are a source of loss, the body constantly losing weight by the carbon lost as carbonic acid, and by the hydrogen lost as water in the breath. Water is also lost, as we shall see, in two other ways: by the skin as perspiration, and by the kidneys as urine, in which, compounds containing another important element, nitrogen, are lost to the body. The lungs supply oxygen only. The carbon, nitrogen, and hydrogen, and the other elements the body requires, are united with one another and with oxygen to form the various substances of which the food we eat consists, and this is the only means by which these elements are supplied. Let us consider now how the body gains these elements by means of the food.

CHAPTER XII

DIGESTION

Food

If bread is analysed it is found to consist of various chemical substances. One of these substances is called glutin. Glutin is a proteid, that is, it is very like the substance albumin and the substance globulin which we have already spoken of as present in blood. Bread also contains starch and a small amount of sugar. These substances mixed in certain proportions with water and a small quantity of certain salts make up bread. In the same way, if lean meat, which is muscle, is examined, it is found to consist largely of proteid matter, with fat and salts, there being also present a considerable amount of water. The substances which are thus found in foods, **food-stuffs**, as they are called, fall into the following classes.

1. **Proteids.** — The chief proteids are: —

Glutin, found in flour and all cereals, peas, beans, potatoes.

Albumin, found in the white of egg, milk, blood.

Globulin, found in yolk of egg, blood.

Myosin, found in lean meat.

Casein, found in milk, cheese.

Fibrin, found in clotted blood.

Gelatin, obtained from bones, tendon, etc., and chondrin, obtained from cartilage, are substances very like proteids.

2. **Carbohydrates.** — Examples: —

Starch, found in flour and all cereals, rice, potatoes.

Sugar, found in bread, potatoes, milk, fruits. There are several different kinds of sugar which, although very like each other, are different chemical substances. The chief sugars are cane-sugar, grape-sugar, malt-sugar, and milk-sugar.

Cellulose, found in fruits, cereals, and all vegetables, forming the walls of the plant cells.

3. **Fats.** — Found in milk, butter, cheese, meat, various oils.

4. **Salts.** — The salts present in foods are very much the same as those found in the body. The chief are the chlorides, phosphates, and carbonates of sodium and potassium, and, to a smaller extent, of calcium and magnesium, with salts of iron and of certain organic acids.

5. **Water.** — Present in all foods.

The body of an animal consists of substances of the same kind as those present in its food, that is, it consists of proteids, carbohydrates, fats, salts, and water. An animal must be supplied with certain elements, namely, those found in the body. The only element which it can take up in the free state is oxygen, and that by the lungs only; the other elements must be received united with one another in the form of definite chemical substances, the food-stuffs. Proteids supply nitrogen, carbon, and hydrogen, carbohydrates and fats supply carbon and hydrogen but no nitrogen. (They all three contain oxygen, but this, being already combined in them with other elements, is not, like the oxygen taken in by the lungs, available for oxidation.) Hence an animal can live on proteids, salts, and water alone (with oxygen derived from the air), for by these it obtains all the elements it requires, and in the proteids the elements are united in a form which it can use for its nourishment. But it cannot live on carbohydrates and fats, for these contain no nitrogen ; moreover, the carbohydrates and fats are not essential, since the carbon and hydrogen which they supply may also be obtained from proteids. An animal can live without carbohydrates and fats, but it must have proteids. Nitrogen is only taken up by the body in the proteids taken as food, and proteids may therefore be called the **nitrogenous food-stuffs.** Some carbohydrates and fats can be made artificially out of simpler substances but with difficulty and at great expense; proteids have never been made artificially at all. Plants have the power of making all these substances out of simpler substances, out of salts, carbonic acid, and water; animals on the other hand cannot do this, hence we see why animals are dependent for their lives on plants.

Daily Loss.—When a man is neither gaining nor losing weight, the amount of material leaving the body must be equal to the amount entering it during the same time. The body, as we shall see, loses material by the lungs, skin, and kidneys, and it gains material by the lungs and from the food taken into the alimentary canal, about one-tenth of which does not enter the substance of the body at all, but merely passes along the alimentary canal and leaves the body again as fæces. The object of the food is to supply the daily loss. The daily loss is the loss of substances containing chiefly the elements carbon, nitrogen, hydrogen, and oxygen. Let us consider the daily loss and supply of the elements carbon and nitrogen. A man taking only a small amount of exercise, loses in a day about 4000 grains of carbon, most of which is lost as carbonic acid by the lungs; for we saw that about eight ounces (3840 grains) might so be accounted for. Of nitrogen he loses in a day only about 300 grains, which leaves the body chiefly in the urea of the urine.

Daily Supply—Mixed Diet.—The man's daily food must supply the 4000 grains of carbon and the 300 grains of nitrogen, and the carbon and nitrogen should be in the right proportion in his diet, so that he need not have to take in more carbon than he wants in order to get the necessary amount of nitrogen, or more nitrogen than he wants in order to get the necessary carbon. If a man were to live on bread alone he would have to eat more than four pounds daily in order to get 300 grains of nitrogen, for bread contains only a small amount of proteid, in which form alone the nitrogen can be taken up. This amount of bread would contain nearly 9000 grains of carbon, so that he would get 4000 to 5000 grains of carbon more than necessary. If a man were to live on lean meat only, which is rich in proteids and therefore in nitrogen, he would have to eat six pounds to get the daily amount of 4000 grains of carbon. This amount of lean meat contains about 1000 grains of nitrogen, so that there would be a waste of 600 to 700 grains of nitrogen. If a man were to live on pure proteids only, on albumin, for instance, he would have to eat a still larger amount of it than this to get 4000 grains of carbon, and there would be a still greater unnecessary consumption of nitrogen. So that, although a man could derive all the necessary elements from proteid food (with water and salts), such a diet would throw much unnecessary labour on the digestive and excretory organs, and some disorder of them would soon occur. We thus see the advantages of a mixed diet, containing some food-stuffs rich in carbon and others rich in nitrogen; and the same applies to the other elements. Some articles of food contain in themselves the various food-stuffs mixed in a suitable proportion for the bodily wants. Milk is one of these.

Milk. — Milk consists of water holding proteids, sugar, and certain salts in solution, and having suspended in it a large amount of fat in a state of division into fine globules. To the fat its whiteness is due. On standing some of the fat rises as cream, and cream shaken till the fat globules run together forms butter. There are two proteids in milk, casein and albumin, which are in solution in much the same way as globulin and albumin are in solution in blood. If a drop of acetic acid is added to diluted milk the casein is precipitated, and as it falls it carries down with it the fat, leaving a clear colourless fluid in which the albumin, sugar, and salts remain in solution. The chief salts present are the chlorides of sodium and potassium and the phosphates of sodium and calcium.

Relative Percentage of Food-Stuffs in Certain Foods

Food.	Water.	Proteid.	Starch.	Sugar.	Fat.	Salts.
Bread	37	8	47	3	1	2
Rice	13	6	79	·4	·7	·5
Peas	15	23	55	2	2	2
Potatoes . . .	75	2	18	3	.2	·7
Flesh (lean) . .	72	19	..	..	3	5
Milk	86	4	..	4	4	.8
Egg	74	14	..	..	10	1.5

The usefulness of foods does not depend merely on the amount of useful food-stuffs they contain, for their digestibility and palatability have to be taken into account. Thus peas contain a larger amount of proteids than meat, and are, moreover, very rich in carbohydrates, yet peas are not so valuable a diet as meat, because they are far less digestible.

The Object of Digestion. — From the cavity of the alimentary canal the useful parts of the food — the proteids, carbohydrates, fats, salts, and water — are **absorbed**, that is, they pass into the tissue forming the wall of the alimentary canal. The wall of the alimentary canal is richly supplied with blood-vessels and lymphatic vessels, and into these vessels the food materials pass; the greater part of them, passing into the blood capillaries, reaches the blood stream at once, while the fats, as we shall see, passing into the lymphatic capillaries, reach the blood in an indirect way, by the thoracic duct, but do eventually reach it. The blood then carries the food materials to the tissues of the body. Before the food materials can thus reach the blood they must be rendered capable of passing into the capillaries or lymphatics by being brought into solution or into a state of division into very fine particles. Moreover, most of the food materials, if they existed in the blood in exactly the same chemical form as in the food, could not be taken up and used by the tissues. The proteids, carbohydrates, and fats must be brought to the tissues as certain particular proteids, carbohydrates, and fats, otherwise the tissues cannot take them up — **assimilate** them, as it is called. Therefore the proteids, carbohydrates, and fats of the food have to be changed to the particular proteids, carbohydrates, and fats respectively which are appropriate to the tissues of the body. By the processes of digestion the food materials are rendered capable of absorption and of assimilation. These changes are chiefly brought about by the action on the food of certain juices which are prepared — secreted, as it is called — by certain tissues, and are poured into the cavity of the alimentary canal. There are four chief digestive juices: the saliva, the gastric juice, the pancreatic juice, and the bile.

The changes which the food undergoes commence in the mouth. It is here masticated by the teeth, and mixed with and acted on by the saliva.

The Teeth. — In the adult there are 32 teeth, 16 in the upper and 16 in the lower jaw, the 8 on one side corresponding to the 8 on the other. Each tooth consists of a crown, and one or more fangs, which are embedded in sockets in the bone of the jaw. The fangs are hollow and contain a vascular tissue called the pulp, and there is a hole at the bottom of each fang by which a nerve and blood-vessels pass to the tooth. The four teeth in the middle of each jaw, two on each side of the middle line, have a chisel-like crown and a single fang. They are the **incisors**. Next to the two incisors in each half of the jaw is a tooth with a more pointed crown and a single fang, which resembles the long pointed teeth of a dog, and is therefore called the **canine**. Next to this are two teeth having a crown of two tubercules, and a fang partly divided into two; these are called the **bicuspids**. Next to these are three teeth with large broad crowns and two or three fangs, called the **molars**, or grinders.

In childhood there is a temporary set of teeth called the **milk teeth**, consisting of twenty teeth, two incisors, one canine, and two molars on each side of each jaw. These are usually all cut by the end of the second year. About the sixth or seventh year the permanent teeth begin to appear and the milk teeth gradually drop out. By the age of thirteen all the permanent teeth are usually cut except the four last molars, that is, the last tooth on each side of each jaw; these are cut much later than the other teeth, sometimes not till twenty-five or thirty years of age, hence are called the wisdom teeth.

Teeth are mainly composed of a substance called **dentine**, a hard, calcified material like bone. Examined microscopically, it is found that dentine does not contain lacunæ and canaliculi arranged in systems as seen in bone, but contains instead a large number of minute tubules arranged parallel to one another in the hard material. The crown of the tooth is capped by a very hard substance called **enamel**, which contains only 2 per cent of animal matter. The dentine of the fangs is covered by a thin layer of bone called **cement**, and this is fixed to the fibrous vascular periosteum which lines the socket in the jaw bone by which the tooth is held.

Mastication and Swallowing. — Mastication or the breaking up of the food by the teeth is carried out by the movement of the lower jaw working one set of teeth against the other, up and down in cutting and biting, and from side to side in chewing. The movements are produced by the contraction of the muscles passing from the fixed bones of the skull to the flat side-pieces of the lower jaw bone. The food thus broken up and mixed with saliva is then collected by movements of the tongue (which is chiefly composed of muscle) and of the cheeks, into a mass and thrust to the back of the mouth; the soft palate is then raised, and as the mass passes the fauces, the sides of the passage, the muscular pillars of the fauces as they are called, contract on it and squeeze it on into the pharynx. The muscular walls of the pharynx then contract on the mass and squeeze it along the pharynx, past the glottis closed by the epiglottis, into the œsophagus, and this, which has also muscular tissue in its wall, carries it on in the same way into the stomach. Fluid is swallowed in a similar manner, by muscular contraction of the walls of the pharynx and œsophagus. For this reason a horse can swallow with its head lower than its stomach, and it is possible for a man to drink when "standing on his head."

The Lining of the Alimentary Canal.—The alimentary canal is lined by what is called **mucous membrane.** A mucous membrane consists of one and sometimes of more than one layer of cylindrical, cubical, or roundish cells closely packed together, underneath which lies loose connective tissue, consisting of fibres and cells and containing blood-vessels and nerves. The part formed by the cubical or cylindrical cells is called an **epithelium.** The epithelium of the greater part of the alimentary canal, of the stomach and the small and large intestine, consists only of a single layer of cells, many of which are of a peculiar nature in so far as they form a slimy material called **mucus.** The epithelium of the mucous membrane of the mouth and œsophagus consists on the other hand of a layer of cubical cells, covered by four or five rows of cells which gradually become flatter towards the free surface. Such an epithelium is called a squamous epithelium. The connective tissue layer with its blood-vessels intervenes between the epithelium and the muscles of the cheeks and other parts on which the mucous membrane lies.

Glands and Secretion.—Here and there in the mucous membrane of the mouth, passing through the epithelium into the deeper connective tissue layer, is a minute tube,

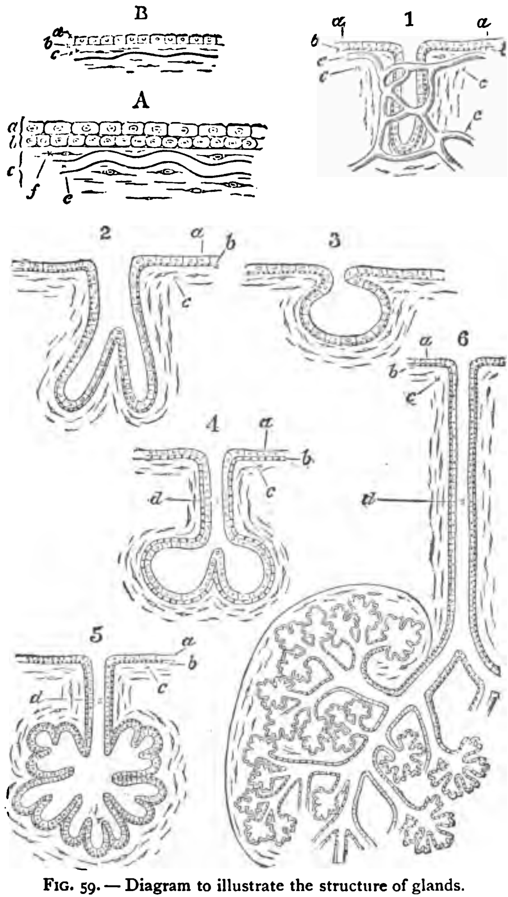


FIG. 59. — Diagram to illustrate the structure of glands.

A, Typical structure of a mucous membrane with two layers of epithelial cells, *a*, *b*; *c*, the connective tissue beneath, with *e*, blood-vessels, and *f*, connective tissue cells. *B*, The same with one layer of cells resting on *b*, the so-called basement membrane. 1, a simple tubular gland; 2, a tubular gland dividing; 3, a saccular gland; 4, a divided saccular gland with duct *d*; 5, a similar gland more divided; 6, a racemose gland, part only being drawn. In Figs. 2–6 the blood-vessels are omitted.

the wall of which is formed of a single layer of small cubical cells, and this leads to a collection of larger cubical cells surrounded by blood-vessels lying in the connective tissue layer. Such a collection of cells is called a **gland**, and the tube its duct. The mucous membrane of the whole of the alimentary canal contains, and indeed is largely made up of, glands. The simplest glands consist merely of a blind tube lined by cubical cells; such simple glands occur in the wall of the stomach. Or the lower end of the tube may be branched, the branches being blind and lined by more or less cubical cells, and all of the branches uniting to form the single tube which proceeds outwards

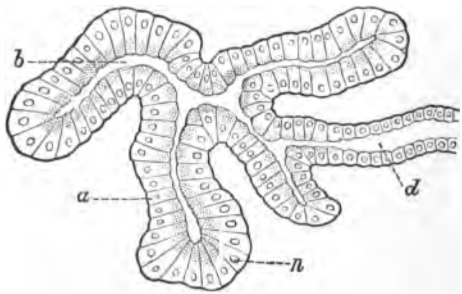


FIG. 60. — Diagram to show the gland cells and beginning of one of the finest ducts of the pancreas.

a, gland cells; *n*, their nuclei; *b*, the cavity or lumen into which the secretion is poured to be carried away by the duct *d*.

to the free opening. If the lower end of the tube branches to a large extent a racemose gland is formed, which consists of clusters of cubical cells forming the walls of minute blind tubes, all of which gradually unite into a single tube, the duct of the gland, opening on the free surface. In some cases many clusters of branched tubes are bound together into a large mass or organ, the whole forming a large racemose gland which may have a duct one or two inches long. An example of such a large racemose gland is the pancreas.

Glands are always well supplied with blood-vessels which lie close to the cells lining the deeper part of the gland.

The function of a gland is to form from the blood a fluid which is discharged along its duct. This process is called **secretion.**

When the cubical cells of glands are examined microscopically they are found to usually contain, in addition to a nucleus, many granules, sometimes fine, sometimes coarse, as we saw was often the case with the white corpuscles of the blood. The granules of material in the cells are made by the living cell substance itself; and when the cells are secreting, water and other substances pass through the cells from the capillaries around them, while at the same time the cells discharge these granules of material, which dissolve in the water and are carried away in solution along the duct. Secretion is not merely due to filtration or exudation from the blood-vessels, but is brought about by the agency of the gland cells, the function of which is to draw certain substances from the blood, and to add to these more or less material of their own manufacture.

FIG. 61.—Dissection to show the salivary glands.

a, the sublingual gland, and *b*, the submaxillary, with their ducts opening into the floor of the mouth by the tongue at *d*; *c*, parotid gland with duct opening into the mouth at *e*.

The glands of the mucous membrane of the mouth secrete a small amount of fluid which is discharged into the mouth, but the saliva is secreted by special glands called the salivary glands.

The Salivary Glands.—The salivary glands are large racemose glands, situated at some little distance from the cavity of the mouth, the ducts leading from each gland to the mouth being about two inches long. There are three pairs of salivary glands: one placed in front of each ear, called the parotid glands; one under the lower jaw on each side, called the submaxillary glands; and a pair situated under the tongue, called the sublingual glands.

Placing food in the mouth, or even the sight or smell of food, will cause a flow of saliva into the mouth. This is brought about by nervous impulses. The sensory nerves of the mouth or the nerves of sight or of smell carry nervous impulses set up in the mouth, the eye, or the nose to the central nervous system; these eventually reach a particular part of the spinal bulb, and the result is that nervous impulses are sent from the spinal bulb to the glands. These nervous impulses, reaching the cells of the glands, cause them to secrete saliva and at the same time lead to a widening of the small arteries of the glands, so that a larger quantity of blood goes to them.

Action of Saliva. — Make a very thin starch paste by boiling a little starch with water and let it cool. Add to a small portion of this some iodine solution. A blue colour results. This is the test for starch. To some of the starch paste add some of your own saliva, and put it in a warm place at about the temperature of the body. In a short time the mixture will become clear, thin, and watery, and a little later will give no blue colour when the iodine solution is added. This shows that the starch has been changed into something else. If instead of adding iodine you add some caustic soda and a drop or two of sulphate of copper solution and then boil, an orange-red colour and precipitate will result. This is an ordinary test for sugar and shows that sugar is present in the mixture. The saliva has turned the starch into sugar. If a little starch paste be held in the mouth for a few minutes, it will taste sweet. While our ordinary food is in the mouth, some, but only a little, of the starch in the food is changed to sugar. The particular kind of sugar which is formed is the same that exists in malt — malt-sugar, as it is called. The saliva has no action on the other food-stuffs. It chiefly serves to moisten the food and so assist mastication.

Saliva consists of water containing, besides certain salts in solution which make it alkaline, some of the slimy substance, mucus, already mentioned, and a peculiar substance called **ptyalin**. Mucin and ptyalin do not exist in the blood; they are made by the cells of the salivary glands. Ptyalin is the substance in saliva which turns starch into sugar. Ptyalin belongs to the class of substances called ferments.

Ferments. — Ferments are divided into two classes — the organised and the unorganised. The organised ferments are living organisms, and an example of such is yeast, which consists of a number of minute cells living in a fluid. Yeast has the power of forming alcohol from sugar, and in the process of brewing the cells act on the malt-sugar in the malt, and from it form alcohol. As the yeast is acting it grows, the cells multiplying by budding off new ones, which themselves rapidly grow and bud in turn. The cells will remain alive after the yeast is dried. If yeast is boiled it is killed, and then it can produce no change. In the manufacture of vinegar advantage is taken of the power of another minute organism to turn alcohol into acetic acid. A large number of processes taking place in nature, such as putrefaction, are also due to organised ferments, minute organisms, or micro-organisms as they are called.

The unorganised ferments are not, like yeast, living cells or micro-organisms capable of multiplying, but chemical substances produced by living cells, and are capable, even when they are separated from the cells which have produced them, of bringing about certain changes in certain substances. This power they retain for a long time under favourable conditions, and, in producing these changes, are not appreciably used up themselves. Those found in the animal body act best at the temperature of the body, and they lose their power after being boiled. Ptyalin is an unorganised ferment. It causes starch to take up and unite chemically with water in such a way as to become changed into sugar. We shall see that nearly all the changes which the food undergoes in the alimentary canal are caused by ferments.

Structure of the Œsophagus and Stomach. — The œsophagus is a tube, the walls of which consist partly of striated partly of plain muscular tissue, lined internally by a mucous membrane which is like that lining the mouth, and in the connective tissue of which are embedded small glands opening into the interior of the œsophagus. The stomach, the walls of which consist of plain muscular tissue lined internally by mucous membrane, may be considered as a dilatation of the alimentary canal. The enlargement is greatest at the left side, forming what is called the cardiac dilatation, because it is near the heart. The right end of the stomach, where it becomes continuous with the duodenum, is called the **pylorus**. The muscular fibres of its walls are here circularly disposed so as to form a band, or sphincter, which by its contraction closes or nearly closes the passage. Outside the muscular coat the stomach is covered with the thin transparent peritoneum, by means of which it is connected with the diaphragm above, and to the abdominal organs near it. This layer of peritoneum on the stomach is sometimes called the third or serous coat. When the stomach is cut open and emptied, its internal surface is found to be thrown into folds, forming prominent ridges, called **rugæ**. The external surface is not thrown in this way into folds. The muscular coat is elastic, and when

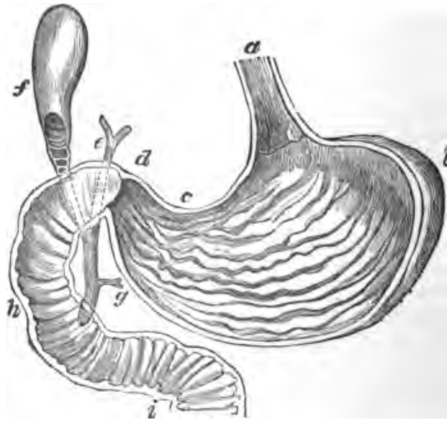


FIG. 62.—The stomach laid open.

a, œsophagus; *b*, cardiac dilatation on left side of stomach; *c*, the upper wall; *d*, the pylorus; *e*, bile duct; *f*, gall bladder; *g*, pancreatic duct, opening with bile duct into *h*, *i*, the duodenum.

the stomach is full and distended, is put on the stretch, shrinking again when the stomach is empty. The mucous coat, on the other hand, does not shrink in the same way, and being only loosely attached to the muscular coat, is thrown into folds when the stomach empties itself and diminishes in size. When the stomach is empty the mucous coat is, as it were, too large for the muscular coat. The mucous membrane of the stomach differs from that of the œsophagus and mouth. Its epithelium, the epithelium at the internal surface of the stomach, consists not of many layers but of a single layer of cylindrical cells. Opening on the surface of the epithelium are a number of simple tubular glands lying side by side; in fact, the mucous membrane is almost entirely made up of these glands packed close together. Each gland is a simple blind tube, the walls of which consist of somewhat cubical cells, to which in the cardiac region a few scattered round or ovoid cells are added, opening at the surface into the cavity of the stomach. Beneath and running up between the tubular glands is connective tissue containing blood-vessels which supply the glands with blood. The connective tissue also connects the mucous layer with the muscular layer on the outer side of it. When digestion is not going on the mucous membrane is pale, its blood-vessels being constricted, but when food reaches the stomach the blood-vessels dilate and the mucous membrane is flushed with blood. The cells of the glands then secrete a juice, the gastric juice, which trickles from the open ends of the tubes into the cavity of the stomach.

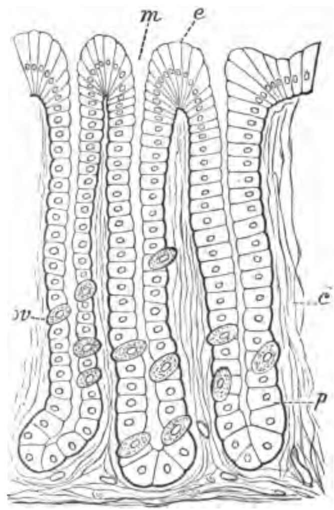


FIG. 63. — Three glands of the stomach — cardiac part.

e, epithelium at inner surface of stomach; *m*, mouth of gland; *p*, principal cells of gland; *ov*, ovoid cells; *c*, connective tissue below and between the glands.

Composition and Action of Gastric Juice. — Gastric juice is a colourless fluid, consisting of water containing in solution a very small amount of salts, a little free hydrochloric acid, and two ferments. The free hydrochloric acid, of which there is about .2 per cent, renders its reaction always acid. The ferments are unorganised ferments and are called **pepsin** and **rennin**. The ferments are formed by the cells of the glands.

Gastric juice has the power of changing proteids into a very soluble form, and, moreover, of changing ordinary proteids such as albumin and globulin, which will not diffuse, that is, will not pass through a membrane from a solution rich in them to a solution poor in them, into a form of proteid which will diffuse. The change is effected by the ferment pepsin, which, in the presence of hydrochloric acid, changes all kinds of proteids into a very soluble and a diffusible form of proteid called **peptone.** Partly on account of these properties, peptone can be more readily absorbed than other proteids.

Obtain the stomach of a recently-killed pig, cut it open and wash it out. Scrape off the soft inner mucous coat, mince this finely, rub it up with some dilute hydrochloric acid (.2 per cent) and put it in a warm place. After a few hours strain off some of the fluid. This fluid will be very like normal gastric juice and will digest proteids quite well. Into some of it put a few shreds of fibrin or a bit of the white of a hard-boiled egg and set it in the warm. In about an hour you will find the fibrin or egg-albumin will have nearly disappeared. It has been turned into the soluble proteid peptone.

Rennin is a ferment which causes milk to clot, and it does this by acting on the casein of the milk in such a way as to make the milk set into a jelly, in much the same way as fibrin ferment acts on the fibrinogen of the blood and causes blood to clot. The material called rennet, which is used in the making of cheese, is obtained from the stomach of the calf, and its use depends on the presence of this ferment.

The Food in the Stomach.—When the food, mixed with saliva, and having perhaps a little of its starch turned into sugar by the saliva, reaches the stomach, the flow of gastric juice which takes place soon renders the whole mass acid. This puts an end to any further action of the saliva on the starch, for ptyalin is destroyed by acid. The contractions of the muscular coat of the stomach, first of one part, then of another, move the food about and thoroughly mix it with the gastric juice as this is being secreted; a kind of churning of the contents of the stomach takes place and the whole is brought to a semi-fluid consistency. During this time the proteids of the food, such as the albumin, globulin, myosin, are acted on by the pepsin whether they have been solidified by cooking (as is the case, for instance, with the white of egg) or still remain in solution, and are in part changed into peptone.

The gastric juice acts only on the proteids; it has no action on the carbohydrates or on the fats. It, however, assists in the digestion of these food-stuffs, because by dissolving the proteids of the tissues taken as food in which they lie it breaks up the material, and so sets the other food-stuffs free. The warmth of the stomach also, to some extent, melts the fats.

After a variable time, which may be one to three or four hours,

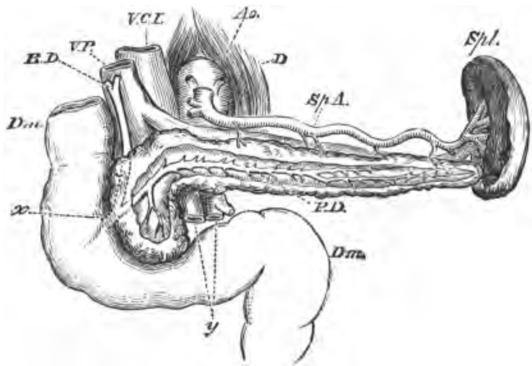


FIG. 64. — The pancreas and spleen.

Spl, spleen with splenic artery *Sp.A*, coming from the aorta, *Ao*. Below the splenic artery is the splenic vein going to the portal vein *V.P.*; *P.D*, pancreatic duct dissected out in the substance of the pancreas opening with *B.D*, the bile duct, at *x* into the duodenum *Dm*. *V.C.I*, inferior vena cava; *D*, diaphragm; *y*, intestinal vessels.

the contents of the stomach, which are called chyme, are allowed to pass on into the duodenum. This is caused by the ring-like muscular tissue of the wall of the pylorus relaxing at intervals and so allowing some of the chyme to be sent on by the contractions of the walls of the stomach.

In the duodenum the chyme is acted on by two juices, the pancreatic juice and the bile.

Structure of the Pancreas. — The pancreas, which secretes the pancreatic juice, lies, as we have seen, in the bend of the duodenum, supported by a portion of the mesentery. It is a large racemose gland like a salivary gland in structure. Its duct passes obliquely through the wall of the duodenum and opens into the interior. By passing through the intestine wall obliquely, a kind of valve is formed, so that the pancreatic juice can pass readily into the intestine, but the contents of the latter cannot pass into the duct.

Composition and Action of Pancreatic Juice. — The pancreatic juice is a colourless, rather viscid fluid, containing, besides a small quantity of proteids, certain salts, the chief being sodium carbonate, which gives it an alkaline reaction. It also contains certain ferments, by means of which it acts on three classes of food-stuffs. It changes starch to sugar, like saliva; proteids to peptone, like gastric juice; and it also acts on fats. These three actions are due to three separate ferments. The ferment acting on starch, turning starch into sugar, is called the amylolytic ferment; the one acting on proteids, turning proteids into peptone, is called the proteolytic ferment, and is also called **trypsin**. The ferment acting on fats is the fat-decomposing ferment, and has the power of decomposing fat into the fatty acid and glycerine of which a fat is chemically composed.

Obtain the pancreas of a recently-killed pig, chop it up very fine, and put it to soak with a little sodium carbonate solution (1 per cent) in the warm; after some hours strain off the fluid. This fluid will be very like normal pancreatic juice, and will convert starch into sugar and proteids into peptone. Prove this in the same way that you did in the case of saliva and gastric juice respectively.

Composition of Bile. — Bile is formed by the liver and is conducted from it by a canal called the bile duct. Before the bile duct leaves the liver it gives off a short side branch which leads to the gall-bladder, situated at the front of the under surface of the liver, and then leaving the liver, passes to the duodenum, where it unites with the end of the pancreatic duct, so that the two form a single tube through the wall of the duodenum, and open together into the cavity of the intestine. When digestion is not going on, the bile formed passes along the side branch of the bile duct to the gall-bladder, where it is stored.

The bile is in man a golden-yellow, in ox and sheep a yellowish-green, alkaline fluid, rather thick and slimy from the presence of mucus formed by the walls of the gall-bladder, and contains, besides the chlorides and phosphates of sodium and other salts which are almost universally met with in the body, certain peculiar salts which are found in it only. These peculiar salts are formed by the combination with sodium of two peculiar organic acids. The salts so formed are spoken of as the **bile-salts**. There is also present a peculiar fatty-looking, crystallisable substance called cholesterin. The yellow or green colour is due to the presence of a colouring matter or pigment, which is formed by the liver from the colouring matter, hæmoglobin, of red blood corpuscles.

Digestion in the Intestine.—When the chyme passes through the pylorus, the pancreas secretes its juice, and as this is gradually poured into the duodenum, a quantity of bile is discharged from the gall-bladder or from the liver at the same time, and the chyme is mixed with these two fluids. The chyme from the stomach is acid, and the first effect of the alkaline bile and alkaline pancreatic juice is to neutralise the chyme and then to make it alkaline. By this any further action of the gastric juice carried along in the chyme is stopped, for pepsin cannot act in an alkaline fluid. The pancreatic juice then acts on the starch which has escaped the action of saliva, and turns it into malt-sugar. No doubt a considerable amount of starch escapes the salivary digestion as the stay of the food in the mouth is short. The amylolytic ferment of the pancreatic juice is very like the ptyalin of saliva, and like it acts in an alkaline medium. Any proteids which have escaped the action of the gastric juice are turned into peptone by the pancreatic juice. The proteolytic ferment of the pancreatic juice is like the pepsin of the gastric juice, but differs from it in being able to act in an alkaline fluid only, while the latter can act in an acid fluid only. The bile has no action on carbohydrates or on proteids, but both the pancreatic juice and the bile act on fats.

Digestion of Fats.—The carbohydrates and the proteids are changed chemically in the process of digestion, and rendered soluble. The fats, on the other hand, are not changed chemically and are not rendered soluble. In the process of digestion the fats are divided into exceedingly fine particles, that is, they are **emulsified**. In milk, fat exists in fine globules, and in this respect milk may be looked upon as an emulsion of fat. If a little liquid fat, olive oil for instance, is briskly shaken up with water, it becomes divided up into globules, but these run together again on standing a few moments, and the oil collects on the surface of the water. If the fat is shaken up with bile instead of with water, the globules do not run together so quickly on standing. If the fat is shaken up with pancreatic juice the fat will remain broken up into fine globules for a longer time still. These experiments show that both bile and pancreatic juice have the power of emulsifying fats, and that this power is the greater in pancreatic juice. The emulsion of fats is then produced chiefly by the direct action of the pancreatic juice. This is, however, assisted by a peculiar chemical change which the pancreatic juice by the fat-decomposing ferment spoken of above produces in a small quantity of the fat. The fatty acid set free by this ferment unites with the alkaline sodium salts of the pancreatic juice and bile, and thus forms a soap, as it is called; ordinary soap being formed by the union of fatty acids with alkalis. So that there comes to be a small amount of a peculiar soap formed in the duodenum. The importance of this is, that when a little, even a very small quantity of a soap is present, the power of the pancreatic juice to emulsify fats is greatly increased, so that under these circumstances, when the juice is mixed with the fat, the latter is divided into exceedingly fine globules.

Structure of the Small Intestine.—The wall of the small intestine consists like that of the rest of the alimentary canal of an internal coat of mucous membrane and an external coat of plain muscular tissue. The muscular fibres of the muscular coat are arranged in two layers. In the internal layer, that next the mucous coat and to which it is adherent by means of connective tissue, the muscular fibres are arranged circularly round the intestine forming the circular layer of muscle, while in the external layer the fibres are disposed along the length of the intestine forming the longitudinal layer of muscle. The external muscular layer is covered by a thin, smooth, transparent membrane, sometimes called the serous coat, which adheres closely to it, and which is continuous with the mesentery and so with the peritoneum in the way already described. The mucous membrane of the small intestine is thrown into folds. These, however, are unlike the folds of the empty stomach spoken of above, since they are present when the intestine is full as well as when empty; moreover, the folds of the mucous membrane of the small

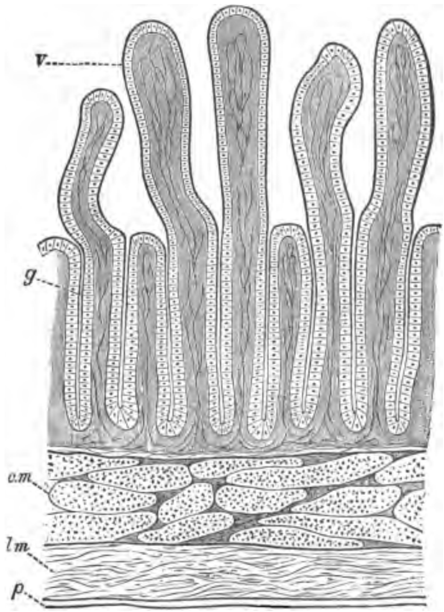


FIG. 65.—Diagram to show the structure of the wall of the small intestine. *v*, villi, and *g*, glands of the mucous membrane; *c.m*, circular muscle layer; *lm*, longitudinal muscle layer; *p*, peritoneum, or serous coat.

intestine are deeper, more numerous, and lie across the length of the intestine. They are called **valvulæ conniventes.** The mucous membrane, which is lined internally by an epithelium, consisting of a single layer of cylindrical cells, is made up of a number of simple tubular glands closely packed together and opening into the cavity of the intestine and of a small amount of a special kind of connective tissue between them. The tubular glands are lined by a single layer of cubical or cylindrical cells. They are called the crypts or **glands of Lieberkühn**, after the man who first described them. In respect to its epithelium, and its glands, the mucous membrane of the small intestine is similar to that of the stomach, but it differs from it in not being level at the surface. The mucous membrane of the small intestine between the glands is thrown up into small finger-like processes, placed thickly together, so that the internal surface is closely beset with them, and this gives the surface an appearance to the naked eye not unlike that of velvet. These processes are called **villi.** Each villus is club-shaped and is covered entirely by the epithelium of cylindrical cells. Under the epithelium the substance of the villus is made up of a kind of fine connective tissue which is continuous at the base of the villus with the similar tissue lying between the tubular glands. In this connective tissue there are numerous blood-vessels, one or more small arteries entering each villus, and breaking up into capillaries, which are collected again into one or more small veins which leave the villus to join with other veins in the wall of the intestine. In the connective tissue at the centre of each villus is an elongated, and sometimes branched space, which is the beginning of a lymphatic vessel, and this, passing out of the villus at its base, unites with other lymphatics in the wall of the intestine, whence it may be traced to the thoracic duct. The lymphatic vessels which thus start in the villi are called **lacteals.**

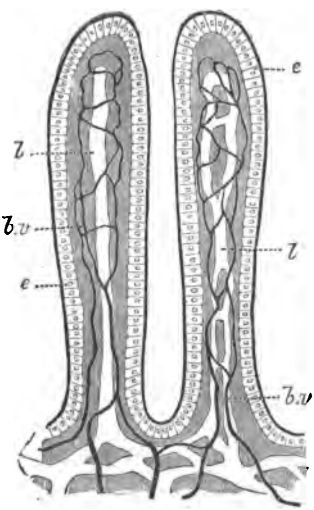


FIG. 66.—Two villi. Highly magnified. *e*, epithelium; *b.v*, blood-vessels; *l*, lacteals.

Here and there in the mucous membrane, in connection with the lymphatic vessels, are found small nodules consisting of leucocytes held in a fine meshwork of connective tissue, that is, nodules having essentially the same structure as lymphatic glands. They are, in fact, minute lymphatic glands. They are called solitary lymphoid nodules. Here and there several of these nodules are collected together forming patches, called **Peyer's patches**, and just over these the villi are absent.

The blood is brought to the wall of the intestine by branches from the aorta, the arteries passing to it along the mesentery. The blood leaves the intestine by veins, lying in the mesentery; these gradually unite with one another, and form, with the veins from the stomach, pancreas, and spleen, the portal vein, which carries its blood to the liver.

Functions of the Mucous Membrane of the Small Intestine. — The chief function of the mucous membrane of the small intestine is to absorb the digested food. This is carried out by the villi. The form of the villi and the presence of the valvulæ conniventes which they beset, enormously increase the extent of surface in contact with the contents. The epithelial cells covering the villi have the power of taking up from the chyme in the cavity of the intestine, peptone, sugar and salts, and also finely-divided fat, as well as water. They have also the power of passing these substances, more or less altered, on to the blood-vessels and lymphatics. The power by which the cells thus transfer material from the cavity of the intestine to the vessels in the wall of the intestine is somewhat akin to the power, which, as we have seen, the cells of a gland have, of allowing only certain substances to pass out of the blood into their secretion. The more diffusible the substances are, the more readily can they, generally speaking, pass through the epithelial membrane; but what substances shall be absorbed and at what rate they shall be absorbed depends mainly on the living epithelial cells. Of these several substances, the peptone, sugar, most of the salts, and a great deal of the water pass into the blood capillaries in the substance of the villi, and so enter the blood stream. On the other hand the finely-divided fat taken up by the epithelial cells passes into the lacteals and is carried away along the lymphatic vessels. Owing to the presence of the finely-divided fat, the lymph of these vessels, instead of being colourless like the lymph in a limb for instance, is after a meal, but only after a meal, milky white, and is called **chyle.** The lymphatic vessels of the intestine, or lacteals, pass away in the mesentery and conduct the chyle, as we have seen, to the thoracic duct, from which it is poured into the blood at the junction of the left jugular and subclavian veins.

The tubular glands of the intestine secrete a small amount of juice, but this is not of much importance for digestive purposes. Cane-sugar taken as food and also the malt-sugar formed by the action of saliva and pancreatic juice are changed into grape-sugar during the act of absorption, and pass into the blood as grape-sugar. The intestinal juice probably helps this change. As the peptone during absorption passes through the epithelial cells of the villi and then through the walls of the blood-vessels into the blood, it is changed into the special proteids present in the blood. The portal vein therefore carries to the liver blood containing water, salts, grape-sugar, and proteids which it has gained from the alimentary canal.

Movements of the Contents of the Intestine. — The contents are gradually moved along the intestine by the contraction of the muscular coat. When the muscle fibres of the circular layer contract at any place the size of the intestine at that place is diminished, and the contents are largely pressed out of that part. The fibres just below this, then, take up the contraction and press the contents farther on. In this way the contraction passes along the intestine like a wave, always travelling towards the large intestine. This kind of contraction is called **peristaltic contraction.** The longitudinal muscular layer assists in the movement. By the time the contents have reached the end of the small intestine much of the material which can be of service to the body has been absorbed. What is left, with the indigestible matter and the remains of the juices, passes in a semi-fluid condition through the ileocœcal valve into the large intestine.

Structure of the Large Intestine. — The wall of the large intestine consists, like that of the small intestine, of an internal coat of mucous membrane, and an external coat of plain muscle, consisting of two layers, an internal circular and an external longitudinal. The muscular fibres of the longitudinal coat differ from those of the small intestine in being chiefly collected into three bands running along the tube. These bands throw the intestine into puckers, which give it a sacculated appearance.

The mucous membrane consists, like that of the small intestine, of an inner epithelium consisting of a single layer of cylindrical cells and of simple tubular glands closely packed together, with fine connective tissue and blood-vessels between them, but it differs from it in there being no villi. There are also no valvulæ conniventes. Solitary lymphoid nodules occur, but these are not collected together into patches.

FIG. 67. — The cœcum and ileo-cœcal valve.

a, ileum; *b*, vermiform appendix; *c*, the opening of the ileum into the cœcum *e*; *d*, the ileocœcal valve.

The rectum is in structure like the rest of the large intestine, except that the muscular coat is much thicker and the glands larger.

Functions of the Large Intestine. — The tubular glands secrete a small quantity of fluid containing much mucin. The chief function of the large intestine is to absorb what is left of the useful material in the digested food, and especially water. The veins carry this to the portal vein. As the contents are passed along by peristaltic contraction of the walls, they become more and more solid as the water is rapidly absorbed, till the remains, consisting of the indigestible matter of the food and the part of the digestive juices which has not been absorbed, is discharged from the rectum as fæces. In the herbivorous animals, which eat only vegetable matter, a certain amount of digestion, especially of the cellulose, or substance forming the walls of the cells of plants, goes on. In man this is unimportant, and the chief changes which take place in the contents of the large intestine are due to the action of micro-organisms, which lead to the formation of organic acids, making the contents acid, and of the substances which give to the fæces its peculiar odour and character.

Diet

Diet in General. — We have seen that although an animal may live on proteids alone with salts and water, it is advantageous that other food-stuffs, such as carbohydrates or fats, should be given to it as well. So far as a man's daily food is concerned it has been found that there are certain proportions in which it is best that the food-stuffs should be taken to enable him to live and work without gaining or losing materially in weight. It is found that a man of average weight remains strong and in good health on a diet which contains somewhere about —

Proteids . . .	100 grammes	(3.5 oz.)
Fats	50 "	(1.7 oz.)
Carbohydrates . .	500 "	(17.5 oz.)
with Salts . . .	30 "	(1 oz.)
and Water . . .	2800 "	(100 oz.)

These figures are taken from the analysis of the daily food of a man living under ordinary conditions in a temperate climate, but under certain circumstances a diet containing considerably less proteid than this would suffice, provided that the fats or the carbohydrates were largely increased. Let us enquire what are the special values of the various food-stuffs.

Proteids. — We have seen that proteids are essential to the tissues, and that it is only in proteids that they obtain nitrogen. We have seen also that the chief waste product in which nitrogen leaves the body is the urea in the urine. When a man is taking in his food as much proteid, but not more than he needs, the amount of nitrogen in the proteid absorbed from the alimentary canal will be about equal to the amount of nitrogen excreted by the urine each day. If the amount of proteid in his food is then increased, there will be a large increase in the amount of urea and other less important substances containing nitrogen in the urine. The excess of proteid food is in part wasted and excreted in the form of urea, and in part so acts on the economy as to lead to a more rapid oxidation or breaking down of the actual tissues of the body. In consequence of this increased oxidation of the tissues more urea is formed from them and at the same time more carbonic acid. A large supply of proteid, by increasing the oxidative changes in the body, leads to a more rapid setting free of energy. This under some circumstances may be advantageous, while under other circumstances may be a wasteful expenditure. So that no hard and fast rule can be laid down as to the exact amount of proteid that the daily food should contain.

When a man is doing heavy labour, the oxidation of the body is increased, and although the muscles, on which the work mainly falls, consist largely of proteids, there is no corresponding increase in the urea, the waste product of proteid oxidation, in the urine. It is the carbonic acid given off by the lungs which is largely increased, so that it appears that when the muscles are in activity they chiefly consume not the nitrogen but the carbon of their tissue substances. A supply of carbohydrate material is at hand, both as glycogen lying in the muscle fibres, and as sugar brought to them by the blood. Such little nitrogeneous waste as is occasioned by muscular activity is due to what may be spoken of as the wear and tear of the muscular tissue rather than to the substances more directly consumed by their activity.

Carbohydrates. — Carbohydrates consist, as we have seen, of carbon united with hydrogen and oxygen in the proportion of two parts of hydrogen to one of oxygen; that is, in the proportion in which they form water. For the complete oxidation of carbohydrates to carbonic acid and water oxygen will be required only for the formation of carbonic acid. We have seen that the volume of carbonic acid given out by the lungs is a little less than the volume of the oxygen taken in, because some of the oxygen unites not with carbon, but with hydrogen and other elements in the body. When an animal is fed on a diet consisting very largely of carbohydrates with only a very little proteid, the volume of carbonic acid given out becomes very nearly equal to the volume of oxygen taken in. On the other hand, if an animal is fed on proteids alone, the difference between the two volumes becomes very considerable, since so much oxygen is used for the oxidation of hydrogen and to a less extent of sulphur and phosphorus, elements also present in most proteids. If the amount of carbohydrates in the daily food of an animal living on a regular diet on which it neither gains nor loses weight be largely increased, without any other change being made, the animal will soon gain in weight. It will be found that the increase in weight is due to the laying on of fat. The large meal of carbohydrates throws into the body more material than can be immediately oxidised, and the excess leads in the first place to a large formation of glycogen in the liver, and then to the formation of fat by the cells of the adipose tissue under the skin and in other parts of the body. Fat so formed and deposited acts as a store of nutriment and will be drawn upon and may be entirely used up by oxidation when the food supply is sufficiently diminished. Carbohydrates constitute a large part of the fattening foods for cattle and lead to fattening more quickly and less expensively than do fats themselves. Fattening cattle are kept as much as possible still and at rest, and this is of service in preventing as far as possible the carbohydrates from being used up, as we have seen that they are, by muscular activity. For similar reasons carbohydrates should be largely avoided and plenty of exercise taken by persons wishing to reduce stoutness.

Fats. — Fats, as we have seen, contain the same elements as carbohydrates, but more than twice as many parts of hydrogen as of oxygen. We have also seen that they give rise, when oxidised, to a larger amount of energy than any other food-stuff. If there is only a moderate amount of fat in the food, it is all oxidised; no fat is stored up in the body. But when the fat in the food is increased, while no other change is made, the body will increase in weight by fat being laid on. Thus the fat of the food may lead to the laying on of fat by the body, and sometimes the actual fat of the food may be, after many changes, deposited by the cells of the adipose tissue, although more usually it leads to fattening indirectly. This it may accomplish by undergoing immediate oxidation and so helping to supply the energy necessary to the body, and by so doing spares from oxidation other food-stuffs, carbohydrates for instance; these are then available for the formation of fat in the body.

Water and Salts.—Water is essential for the various chemical processes going on in the body. Besides being obviously necessary to supply the water lost by the lungs, the skin, and the kidneys, the processes of secretion and of excretion cannot go on without it. Again, water is necessary for the action of the ferments of the digestive juices, and in many cases the change which the ferments effect is due to the union they bring about of the elements of water with the substance, such as starch or proteid, they act upon. Some of the salts of the body are closely united with the proteids of the tissues, and cannot be completely separated from them without destruction of the proteids. They are absolutely necessary for the chemical processes going on. Alkaline salts, such as sodium carbonate, are of use, among other services, to neutralise acids formed by proteid oxidation, and to furnish a proper alkaline reaction for the activity of pancreatic juice. Common salt, which is met with everywhere, furnishes the chlorine for the formation of hydrochloric acid by the stomach. But the services of the salts cannot be stated in a few words, for they serve many different purposes in the body, being intimately connected with the complex chemical changes going on. Some salts, such as phosphate and carbonate of lime, are, as we have seen, deposited in bones to render them firm and serviceable as supporting structures.

A Purely Vegetable Diet. — Carbohydrates are almost exclusively derived from the vegetable kingdom, and vegetable proteids, such as the so-called glutin of wheat and legumin of peas, and vegetable fats, such as oils of nuts and fruits, can completely take the place of animal proteids and fats. Vegetable proteids and fats undergo in the body similar changes to animal proteids and fats, but their digestion is not so easy or so complete. Moreover, since vegetables, as a rule, contain a relatively small quantity of proteids, a larger diet has to be taken to obtain the necessary amount of daily proteids when the diet is a purely vegetable one. All vegetable food contains, in addition, a large amount of material which for man at least is not digestible, or only slightly digestible, such as cellulose. Hence a purely vegetable diet has to be more bulky than a mixed diet, and there is a larger undigested remnant discharged from the rectum. Man can adapt himself to a purely vegetable diet, and in fact many races live exclusively on such food; but a mixed diet, one containing some animal proteids and fats, is, under ordinary circumstances, the best.

Alcoholic Beverages. — Ordinary alcohol is an organic compound of the composition C_2H_6O. It occurs in the following proportions in the following beverages: —

Beer	about	5	per	cent.
Light wines (claret, hock)	"	10 to 15	"	"
Strong wines (sherry, port)	"	20	"	"
Spirits	"	30 to 70	"	"

When alcohol is taken into the body, most of it is oxidised and gives rise to energy. The amount of energy thus supplied, compared with that of the other parts of the food, is insignificant, and the effect of alcohol depends not on the energy which it supplies, but on the influence it exerts on the changes going on in the several tissues. The value of the various articles of diet does not depend by any means solely on their ability to supply energy; we have seen, for instance, that salts which supply no energy are nevertheless of use in directing the changes going on in the body. In a somewhat similar way alcohol and other substances may influence and direct these changes. Whether that influence is beneficial or no will depend upon many circumstances, and certainly upon the quantity taken. We have many illustrations that a substance taken into the body in a certain quantity will produce one effect, and in another quantity it may be quite an opposite effect. There is no doubt that a certain quantity of alcohol is injurious and interferes with all the functions, and ultimately brings about various diseases, but it does not follow from this that in a smaller quantity it may not be harmless or even beneficial.

Alcohol produces its most marked effects on the vascular and nervous systems. It leads to a dilation of the small blood-vessels of the skin, and so to a larger flow of blood to the surface of the body; this, while it produces a sensation of warmth, leads to an increased loss of heat by radiation and perspiration. If the amount of alcohol taken is excessive, the loss of heat will lead to a definite fall of temperature. Alcohol is then of no service as a preventative against cold.

Alcohol makes the heart beat more quickly and makes it do more work in a given time. In some cases this may be beneficial, but generally it is a wasteful and useless expenditure of energy. Alcohol diminishes the power of doing prolonged muscular work, and large quantities lead to a great diminution in the force of muscular contractions.

The effect of alcohol on digestion is very complex. When taken with food it leads to a diminution in the rate and completeness of digestion, if it is present in any but very small quantities. If some proteid (white of egg or fibrin) is put in a flask with some gastric juice, it is found that if a very little alcohol (1 part to 500 of the mixture) be added, the digestion will go on a trifle more rapidly, but if the alcohol added much exceeds this amount, a well-marked retardation is produced. It does not follow that such a small amount of alcohol is useful in ordinary digestion, because when it is taken into the stomach we have to consider the influence it has on the secretion of gastric juice, on the movements of the stomach, and on absorption. A small quantity of alcohol appears, however, to encourage the secretion of gastric juice, but large quantities act injuriously on all the processes of digestion.

A small amount of alcohol may promote the action of the central nervous system, and often appears to quicken the rapidity of thought and to excite the imagination, but more usually, and always when taken in any but small quantities, it diminishes the power of connected thought and judgment. It also diminishes the power of receiving sensory impressions, and at the same time blunts all the special senses. Since it reduces the sensibility to cold and fatigue and allays mental pain and worry, it is often resorted to, and then with great danger.

The limit up to which any beneficial effects are produced by alcohol is soon reached, and beyond that it only does harm. This limit is not the same for all individuals; a quantity good for one may be injurious for another, and a large number of people find that strictly moderate quantities of alcoholic beverages do them no harm, while others find that similar amounts impede them in their daily work.

The effect of alcoholic beverages does not depend solely on the ordinary alcohol in them, for other substances which they contain often have powerful actions in the body. The habitual use of such beverages to excess greatly shortens life by inducing diseases of many organs. In some cases of disease alcohol may be of great service, but in health it cannot be considered a necessity, and is far more potent for evil than for good.

CHAPTER XIII

THE LIVER AND SPLEEN

Structure of the Liver. — The liver, the upper surface of which is convex, lying immediately under the dome of the diaphragm, is a large dark-red organ about fifty ounces in weight. It is covered by a layer of peritoneum, closely adherent to it, by which it is attached to the diaphragm and other structures. It is divided into two parts or lobes, a right and a left. The right lobe, which is much larger and thicker than the left, is less distinctly divided by grooves or fissures on its under surface, giving rise to three more small lobes between the right and left, so that there are five all together. The most conspicuous of the fissures on the under surface is called the portal fissure. At the portal fissure three vessels pass into the liver: the **hepatic artery**, which brings arterial blood from the aorta; the **portal vein**, which brings venous blood from the stomach, intestines, spleen, and pancreas; and the **bile duct**, which carries the bile from the liver to the duodenum. As these vessels are traced inwards, they gradually

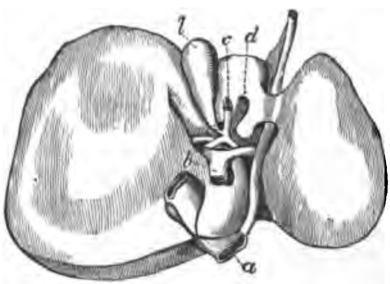


FIG. 68. — The liver turned up and viewed from below.

a, inferior vena cava, overlapped by a small portion of the liver; *b*, portal vein; *c*, bile duct; *d*, hepatic artery; *l*, gall-bladder. The hepatic vein is not seen.

branch and divide, keeping one another company, being loosely bound together by a little connective tissue. The liver tissue itself is composed of cubical or many-sided cells, the **hepatic cells**, closely packed together. The hepatic cells, each of which is about $\frac{1}{1000}$th of an inch in diameter, are grouped into small many-sided masses, nearly $\frac{1}{10}$th of an inch across, called **lobules**. On the surface of the liver of the pig, five or six-sided areas marking out those lobules which are on

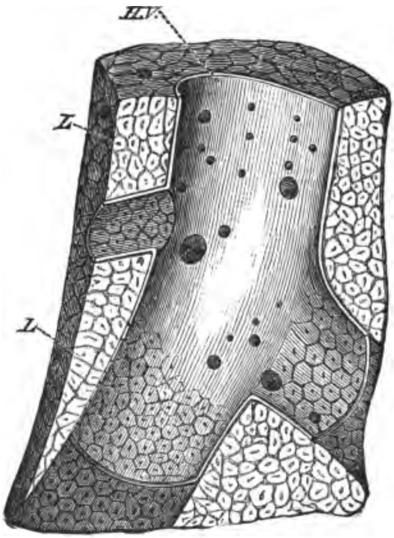


FIG. 69.—Section of a piece of liver showing a branch of the hepatic vein cut open *H.V*, hepatic vein branches; *L*, areas showing the lobules of the liver.

the surface can be seen with the naked eye. The lobules are separated from one another by a little connective tissue, which is continuous with the connective tissue round the branches of the portal vein and hepatic artery. The branches of these vessels can be traced in this connective tissue between the lobules to the borders of each lobule, and there they break up into capillaries, which stream towards the centre of the lobule. The capillaries of the hepatic artery join with those of the portal vein, so that the distinction between one system and the other is lost in the lobule, and the blood of one is mixed with that of the other. The capillaries proceeding in this way from the periphery to the centre of each lobule lie between rows of the hepatic cells. In the centre of the lobule the capillaries open into a vein which passes out of the lobule and unites with similar veins from neighbouring lobules; and in this way larger veins are formed, which finally unite to form

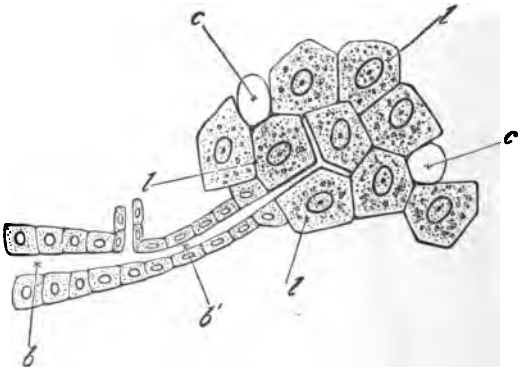


FIG. 70. — Diagram to show the termination of a fine bile duct.

b, small bile duct becoming still finer at *b'*; *l*, hepatic cells; *c*, capillaries cut across.

the **hepatic vein**, which carries the blood from the liver to the inferior vena cava.

The branches of the bile duct, which consist of an internal layer of columnar cells covered by a sheath of connective tissue, can also be traced to the edge of the lobules, where they begin as fine but distinct ducts, formed of a single layer of cubical cells; but these fine ducts are in communication with minute, cleft-like passages between the hepatic cells of the lobules. The fine passages between the cells of each lobule unite to form the fine ducts just spoken of, which again unite, forming larger ducts lying between the lobules, and these unite with one another until the main bile duct is formed. The bile duct which leads to the duodenum has, as we have said; close to the liver, a side tube, which goes to the **gall-bladder,** A

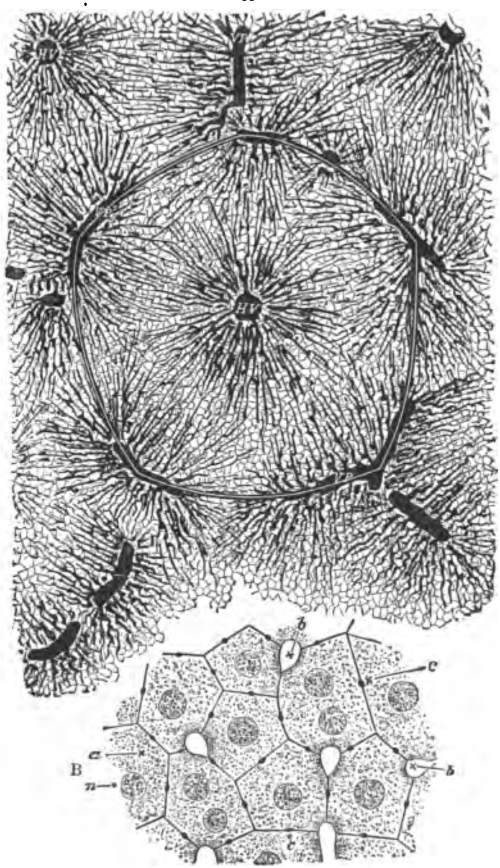


FIG. 71.

A, section of liver with blood-vessels injected. *H.V*, vein in the centre of a five-sided lobule joining with others to form hepatic vein. From the edge of the lobule vessels stream in from branches of *V.P*, the portal vein. The outlines of the liver cells are seen as a fine network.

B, part of a lobule highly magnified. *a*, liver cell with nucleus *n*; *b*, capillaries cut across; *c*, minute bile passages between the cells cut across seen as black dots.

situated on the under side of the anterior edge of the liver.

The Functions of the Liver.—The secretion of bile is one of the functions of the liver. It is formed by the hepatic cells. These draw the substances they require from the blood in the capillaries of the lobule, and they themselves make the special bile salts and pigments of the bile. The bile so formed passes from the hepatic cells into the minute passages between the cells, thence to the small bile ducts between the lobules, and so to the main duct. The bile is always being formed, and in this respect its secretion differs from that of the saliva, gastric juice, and pancreatic juice, which are generally formed only when food has been taken. When digestion is not going on the bile passes into the gall-bladder, and is sent on from the gall-bladder into the duodenum only when it is wanted to act on the chyme. The quantity of bile secreted in twenty-four hours is about two pints.

Another function of the liver is to store up carbohydrates. The portal vein brings to the liver a large quantity of sugar which has been absorbed in the intestines. The sugar is in solution in the plasma of the blood of the portal vein. Some of this sugar passes out of the capillaries in the liver with the lymph which exudes through the capillary walls, and is taken up by the hepatic cells which then make out of the sugar a starch-like substance called **glycogen**, storing it up in the substance of the cells in the form of granules or small masses. Glycogen is far less soluble than sugar, and it is stored in the hepatic cells in the solid condition. Much of the carbohydrates absorbed from a meal are in this way taken up and stored in the liver—are, in fact, intercepted on their way to the general circulation. By this means the blood of the general circulation is prevented from becoming too rich in sugar, as it would otherwise be after a good meal. Sugar is one of the substances which the blood brings to the tissues; there is always a small quantity of sugar in the blood, and as this is used up some of the glycogen in the liver is turned into sugar, and is discharged from the liver cells into the blood. In this way the sugar in the blood is always kept at the proper amount. The liver lays down most glycogen after a meal containing much carbohydrate food has been taken. But an animal can live on proteids only (with salts and water), and if plenty of proteid is given, the liver will lay down some glycogen. This is because it is the property of the liver cells to make glycogen, and they can make it if they are supplied with proteids only, but they can make it much more plentifully from sugar. A small quantity of glycogen is also found in muscle.

The Spleen

Structure of the Spleen. — The spleen is a dark purplish-red organ about five inches in length, situated, as we have seen, on the left side of the abdomen just below the stomach. It is soft and spongy in texture, that is, is made up like a sponge of a close branching meshwork. The meshwork consists of fibrous and elastic tissue, to which is added in man and in most animals a number of plain muscular fibres. A layer of the same tissue on the outside, called the capsule, encloses the organ. In the meshes of the sponge work is a soft pulpy tissue called the spleen-pulp. The spleen-pulp consists of red blood corpuscles and of colourless cells, some of which are branched, while others are small and round like the leucocytes or colourless corpuscles of the blood. Here and there the leucocytes are densely crowded together, forming small white nodules. If the spleen of a sheep or ox is cut across these nodules are seen as round white spots in the dark-red pulp. The spleen is well supplied with blood by an artery, the splenic artery, which branches almost directly from the aorta. The smallest branches of the artery open directly into the spleen-pulp. From the spleen-pulp the blood is collected by small veins which gradually unite, forming the splenic veins which carry the blood away to the portal vein and so to the liver.

Functions of the Spleen. — The spleen changes much in size. It becomes largely distended with blood about five or six hours after a full meal, and later on shrinks again. Sometimes it varies in size regularly every two or three minutes, due to the contraction of its plain muscular fibres causing a shrinking, and their subsequent relaxation causing a return to the larger size again.

In the nodules of the spleen the leucocytes multiply. This is brought about by the division of a leucocyte into two, which grow and in their turn divide. Some of these leucocytes pass away from the spleen-pulp by the veins. The spleen therefore, like the lymphatic glands, supplies colourless corpuscles to the blood. Some of the red corpuscles of the blood in their passage through the spleen, probably those which are old and worn out, are entangled in the spleen-pulp, where they undergo change and gradually break up. The colouring matter of these broken-up red corpuscles is carried away from the spleen in the blood to the liver, and is used by the liver to make the colouring matter of the bile.

CHAPTER XIV

WASTE AND EXCRETION

WE saw that the essential characteristics of living tissues are that they are constantly undergoing oxidation, and constantly building up their substance anew. We have seen how the blood obtains and supplies them with oxygen, and that the blood derives all the other substances they require from the food in the alimentary canal. We have seen also how the crude substances in the food are acted on and prepared by the various digestive juices, and that some of the substances are further modified as they are being absorbed by the epithelial cells of the intestine. Certain substances in the blood coming from the alimentary canal, especially the carbohydrates, are further acted on by the liver. The blood is also influenced during its circulation through other organs such as the spleen, so that it is brought into and kept in a condition fit for the proper nourishment of the tissues.

The oxidation which the tissues are constantly undergoing is a process of waste. The living substance takes up oxygen, and the oxygen unites with the elements or groups of elements of which the living substance is composed, and is given off again in union with them in the waste products. The chief of these waste products are carbonic acid, water, and urea. These substances which are made in the tissues pass from the tissues into the blood. Just as the tissues derive all their nutrient matter and oxygen from the blood, so they return to the blood their waste products. These substances being injurious to the tissues have to be got rid of; they must be removed from the blood and be discharged from the body. They have to be **excreted** as it is called. Excretion is the removal from the blood of substances which are to be discharged from the body. There are three chief excretory organs, the lungs, the kidneys, and the skin. Of the three chief waste products, the carbonic acid is removed from the blood by the lungs, the urea and other nitrogenous waste substances by the kidneys, and water, with other substances, by the skin and by the lungs and kidneys as well. The lungs, besides removing carbonic acid from the blood, supply oxygen to the blood, while the kidneys and the skin supply nothing.

The Urinary Organs

The **kidneys** — situated in the abdomen, one on each side of the lumbar region of the vertebral column — are dark-red organs 4 inches long and 2½ inches across, and are flattened so that they are not much more than an inch in thickness. The inner edge of each kidney, that is, the edge next to the vertebral column, is concave, while the outer edge is convex. The concavity at the middle of the inner edge is called the hilus, and there the arteries enter the kidney and the veins leave it. The arteries are derived from a single vessel — one for each kidney — which springs from the aorta. The veins unite into a single vein from each kidney, and this empties its blood into the inferior vena cava. From the hilus of each kidney there proceeds another vessel, the **ureter**. The ureters are narrow whitish-looking tubes, about 15 inches long. They pass to the bladder. The **bladder**, situated in the pelvic cavity, or the lowest part

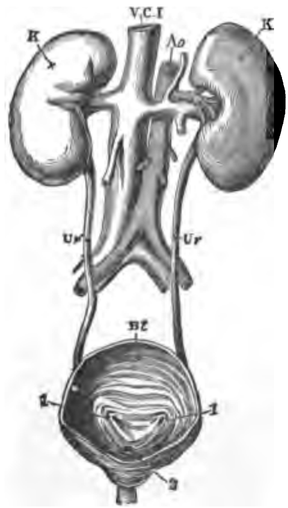


FIG. 72. — The urinary organs.
K, kidneys; *Ur*, ureters; *Bl*, bladder; 1, openings of ureters, and 2, opening of urethra in the bladder; *Ao*, aorta; *V.C.I.*, inferior vena cava.

of the abdomen, is a bag, the walls of which are composed of plain muscular tissue, lined internally by a layer of mucous membrane. It occupies very little space when it is empty, but can be distended to a large size. When moderately distended it will hold a pint.

The function of the kidneys is to secrete urine. The function of the ureters is to conduct the urine from the kidneys to the bladder. The function of the bladder is to store the urine and to discharge it at intervals. The ureters pass obliquely through the wall of the bladder to open into its interior, and this assures a valve-like closure of the openings, so that urine can always trickle into the bladder, but cannot be forced back again from the bladder into the ureters. The tube leading out of the bladder is the **urethra.** Around the opening from the bladder into the urethra are a number of plain muscular fibres circularly placed, forming what is called a sphincter muscle. These muscular fibres are kept contracted, and so the opening is kept closed. The bladder, when a quantity of urine has accumulated in it, can be emptied at will, the sphincter muscle is relaxed, and the contraction of the muscular fibres of the bladder drives the urine out along the urethra.

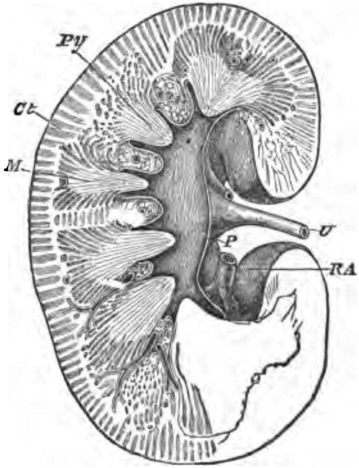


FIG. 73. — Section of the kidney.
Ct, cortex; *M*, medulla; *Py*, pyramids; *P*, pelvis; *U*, ureter; *RA*, renal artery.

Structure of the Kidney. — Obtain a kidney of a sheep. Notice its concavo-convex shape. There is often some fat on the surface, especially at the hilus. Carefully remove the fat little by little from round the hilus, and look for the whitish ureter and the reddish (from remains of blood) artery and vein. With scissors cut into the hilus, or, if you can, cut open the end of the ureter along its length and trace it into the kidney. The ureter dilates in the kidney into a funnel-shaped cavity called the **pelvis of the kidney.** The inner wall of the cavity is whitish, except for masses of the reddish substance of the kidney projecting into it. These projections into the pelvis are called the **pyramids** of the kidney. If you look carefully you will see that they are finely pitted on the surface. These pits are the openings of the minute **tubules** of which the substance of the kidney is composed. Cut the kidney in two halves, on the flat, cutting from the hilus towards the convex border. The outer part of the kidney is of a different colour from the rest, being a darkish-brown, while the central part or portion near the pelvis is paler and shows bright red blood-vessels. The outer part is called the **cortex**, and the part between this and the pelvis is called the **medulla**. Notice that the small blood-vessels of the medulla appear to radiate from the cortex towards the pelvis, being best seen close to the cortex. This is because the main arteries which have come into the kidney at the hilus go to the region between the medulla and the cortex and there break up into fine branches, which run on the one side into the medulla, where they can be distinctly seen because they lie nearly parallel to one another, and on the other side into the cortex, where they are not well seen because they run in a very irregular way. These vessels lie between the tubules which form the substance of the kidney. Traced back from their openings in the pelvis, the tubules can be seen by the microscope to lie parallel to one another in the medulla, and to greatly increase their number by branching. At the limit of the medulla the tubules pass on into the cortex, where they at once take a very irregular and tortuous course,

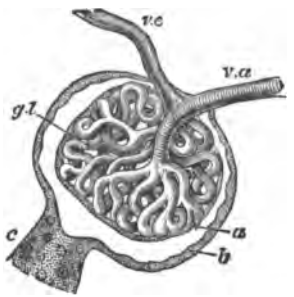


FIG. 74. — A Malpighian capsule.

v.a, small artery entering and forming the glomerulus *gl*, and finally leaving in a small vein, *v.e*; *c*, tubule; *a*, epithelium over the glomerulus; *b*, epithelium lining the capsule.

and finally end in the cortex by blind dilated extremities. The blind dilated extremities are, however, in reality the beginnings of the tubules, and the openings in the pelvis are their ends. The closed dilated extremities are called **Malpighian capsules**.

The wall of a tubule consists of a single layer of epithelial cells. These cells vary in shape in different parts of the same tubule, but are mostly cubical, and they occupy so much of the tubule that the bore is small. At the dilated extremity the wall of the tubule is very thin, and at the extreme end this thin wall is pushed in, as it were, by a small cluster of blood-vessels, called a **glomerulus**. A Malpighian capsule therefore consists of the closed dilated extremity of a tubule into which is projecting a cluster of capillaries covered by the thin wall of the tubule. To each glomerulus proceeds a small artery, and from each proceeds a small vein. This small vein, however, does not at once join other veins, but breaks up into capillaries which join with the capillaries lying round the tubule, and it is from these the veins arise which gradually unite into veins which form the main vein leaving the kidney at the hilus.

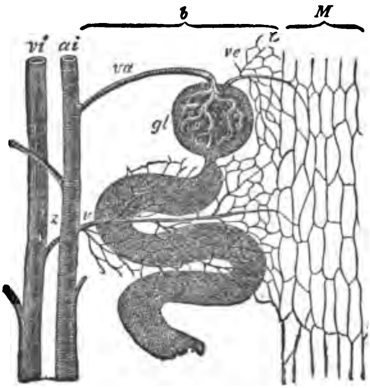


FIG. 75.— Diagram to illustrate the circulation in the kidney.

ai, small artery giving off the branch, *va*, to glomerulus, *gl*, from which the vein, *ve*, issues. This breaks up into capillaries, which surround the tubule and unite up into a small vein, *v*, which joins the vein, *vi*. *M*, capillaries around tubules in parts of the cortex where there are no glomeruli; *b*, parts of the cortex where there are glomeruli.

Composition of Urine.—The amber-coloured fluid, urine, consists of water holding certain organic and inorganic substances in solution. The chief organic substances contain nitrogen, and the most important of them is **urea**. The chief inorganic substances are the chloride, sulphate, and phosphates of sodium and, in smaller quantity, of potassium. Some salts of calcium and magnesium are also present. Urine is acid in reaction, due to the presence of the acid phosphate of sodium. From two to three pints of urine, weighing about fifty ounces, are excreted in twenty-four hours. This contains rather more than one ounce of urea, while the salts and other substances make up about another ounce of solids.

Urea is a compound having the composition CON_2H_4; 60 parts by weight of urea contain 28 parts of nitrogen, so that nearly half the weight of urea is nitrogen. In a man taking just as much food and not more food than he ought, the

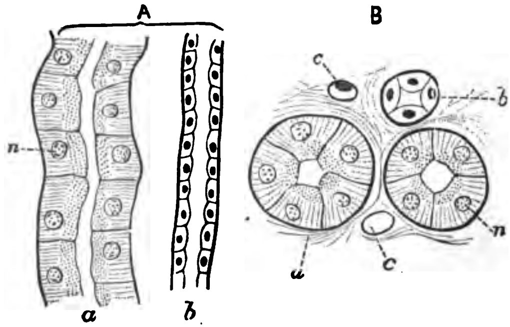


FIG. 76.—Tubules of the kidney.
A, cut lengthwise. B, cut across.
a, tubule where secretion goes on; *b*, conducting part of tubule; *n*, nuclei; *c*, in B, capillaries cut across.

amount of nitrogen leaving the body is about equal to the amount taken in, though it may be a little more or a little less according to circumstances. We have taken the amount of nitrogen leaving the body daily to be in round numbers 300 grains, and one ounce and a quarter of urea, about the amount excreted in a day, will contain very nearly the whole of this. The small remainder of the nitrogen is excreted by the urine in other substances, of which one of the chief is **uric acid**. Uric acid occurs only in small amount in the urine of man and of animals which suckle their young, though it is the chief nitrogenous waste product in reptiles and birds; in these animals urea is absent and uric acid takes its place.

Excretion of Urine.—The blood passing through the capillaries which form the glomerulus of a Malpighian capsule is only separated from the cavity of the tubule by the thin wall of the capillaries, and by the layer of very thin flattened cells, the part of the wall of the capsule which covers them. Water with certain salts in solution passes from the blood through these two thin membranes into the cavity of the capsule. The thin epithelial membranes allow the water and certain salts of the blood to pass through, but will not allow other substances, such as the albumin, to pass. The process is, therefore, not a mere filtration, such as takes place through blotting paper, through which all substances in solution can pass. The epithelial membrane consists of living cells, and these decide what shall pass, and what shall not. Part of the urine is thus derived from the blood passing through the glomeruli. From the Malpighian capsules the fluid travels along the tubules, following the winding course in the cortex, and the straighter but still complicated course in the medulla, till it is discharged, at the united opening of several of the tubules, into the pelvis of the kidney. As it passes along the tubules, the urea and some other substances are added to it by the agency of the epithelial cells which form the wall of the tubules. These epithelial cells separate the urea and the other substances from the blood in the capillaries around them, and pass them on into the interior of the tubule. The urea already exists, though in minute quantity, in the blood as it flows to the kidney, so that these cells do not make it, but merely let it pass out into the tubules. Some of the less important substances which leave the blood by the kidney are modified and changed into other substances as they pass through the epithelial cells of the tubules.

The amount of urine formed depends chiefly on the quantity of blood which is sent through the glomeruli. The greater the amount of blood sent to the kidney, the greater is the flow of urine. In cold weather more urine is passed than in warm weather. This is because cold causes a constriction of the blood-vessels of the skin, and so less blood reaches the surface of the body, while more is sent to the internal organs and so to the kidneys. Hot weather, on the contrary, causes a dilation of the vessels of the skin; more blood is sent to the surface and less to the internal organs. More urine excreted means only more water discharged from the blood by the kidneys, for the amount of urea and other substances discharged in a day does not vary much as the result of changes of temperature; it is the amount of water discharged with these substances which chiefly varies. When in cold weather less water leaves the body by the skin as perspiration, more leaves by the kidneys, so that the skin and the kidneys work, in this respect, hand in hand. The presence of much water in the blood, such as is brought about by drinking a large quantity of fluid, leads also to an increase in the flow of urine.

CHAPTER XV

THE SKIN

THE skin consists of two layers, the outer called the **epidermis**, and the inner called the **dermis**.

The skin is thickest on the soles of the feet and palms

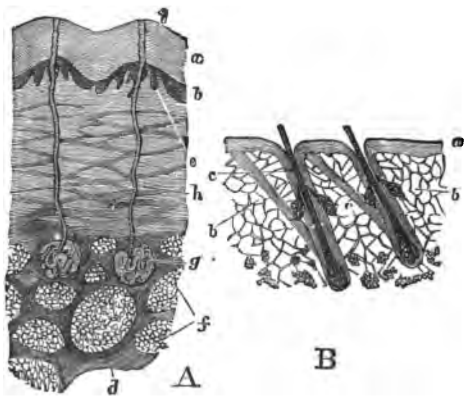


FIG. 77. — The skin.

A. — Section of skin showing sweat glands. *a*, epidermis; *b*, its deeper or Malpighian layer; *e*, *d*, dermis; *f*, fat; *g*, sweat glands; *h*, ducts; *i*, opening of duct on surface.

B. — Section of skin showing hairs and sebaceous glands. *b*, fine muscles connected with the hair sheaths, *c*.

of the hands, and on the back, where it may be as much as a quarter of an inch thick.

The **epidermis**, or cuticle, is formed of many layers of cells. The deepest layer consists of elongated or columnar cells, lying perpendicularly side by side. The layers immediately over this consist of cells which are shorter and many-sided or round in shape. The cells over these gradually become flatter and flatter till those of the surface layers are reduced to mere thin scales. In the deeper parts of the epidermis the cells are soft and protoplasmic and contain a nucleus. This forms what is called the **Malpighian layer.** In the superficial part the nuclei of the cells disappear, and the cells gradually become hard and horny. This forms what is called the **corneous layer.** The dry scales at the surface are gradually worn away and shed. The flattened cells below these are pressed up to the surface as new cells are formed by the division and multiplication of the cells of the deeper layers. The dark colour of the skin of the negro is due to granules of a dark pigment in the lowest cells of the Malpighian layer of the epidermis. The Malpighian layer is firmly attached to the dermis, but the corneous layer, as in a blister, may separate from the Malpighian layer.

The **dermis**, or corium, on which the epidermis rests, consists of a fine but strong network of connective tissue, in which a large number of yellow elastic fibres, many fine, but some coarse, are mixed with the white fibres; connective tissue cells are also present in it. The surface of the dermis is not even but thrown up into a number of small conical processes which project into the epidermis, and so make the lower edge of the epidermis irregular. These processes are called the **papillæ** of the dermis. The outline of the epidermis does not follow the outline of the papillæ, so that these are not evident at the surface of the skin. Besides the papillæ the dermis, and with it the epidermis, is thrown up into comparatively large ridges easily seen by the naked eye, and in many places the skin is folded and creased.

The deeper part of the dermis is connected to the tissues under the skin, such as muscle or bone, by a very loose connective tissue of varying thickness, spoken of as the subcutaneous tissue. This usually contains a considerable quantity of fat, filling up the inequalities left by structures below and giving roundness to the limbs. This layer is particularly thick under the skin of the abdomen.

The dermis is very vascular, that is, it is well supplied with blood-vessels. These are especially abundant in some of the papillæ, where they form loops of capillaries just underneath

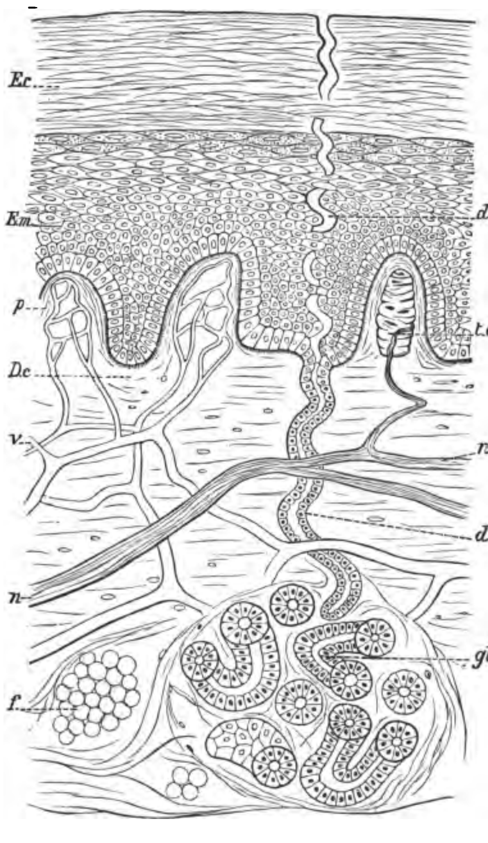


FIG. 78. — Diagram to show the structure of the skin.
E.c, epidermis corneous part; *E.m*, epidermis Malpighian part; *D.c*, connective tissue of dermis; *p*, papilla; *gl*, sweat gland, the coils of the tube cut across or lengthwise; *d*, its duct; *f*, fat; *v*, blood-vessels; *n*, nerve; *t.c*, tactile corpuscle.

the epidermis. No blood-vessels run into the epidermis itself. The dermis is well supplied with nerves. Some of these end in peculiar round or oval structures in some of the papillæ, as well as in the deeper parts of the dermis. Very fine fibrils from some of the nerves pass into the epidermis and end there in the deeper layers. Most of these nerve fibres are for conveying to the brain nervous impulses arising in the skin, which lead to such sensations as touch, temperature, and pain. They will be considered more fully in connection with the special senses.

The Glands of the Skin. — If the skin of the palm of the hand is examined with a lens, a row of pits or depressions will be seen on the ridges. These are the pores or openings of the **sweat glands**. Each pore leads by a spiral or corkscrew-like tube through the epidermis into the dermis. In the dermis the tube, the wall of which is here formed of a single layer of cubical cells, is continued down to the deeper part of the skin, and there its blind end becomes coiled into a kind of knot. This coiled part is a sweat gland. The cells are larger in the coiled part of the tube than elsewhere, and among the coils are numerous blood-vessels. These cells secrete from the blood the sweat, which is then conducted along the tube to be discharged on the surface of the skin. Minute droplets of sweat can with a magnifying glass be often seen at the separate pores.

Other glands, namely the **sebaceous glands**, are present in the skin, and are also situated in the dermis. They are much smaller than the sweat glands, and are always connected with hairs. Each consists of a short duct leading to a small sac lined with and indeed filled with cells. The duct opens into the depression in the skin or follicle, as it is called, in which a hair lies. The secretion is fatty in nature.

Composition and Secretion of Sweat. — The sweat or perspiration consists of water containing a very little dissolved solid matter. This is composed chiefly of common salt and certain organic bodies of an acid or fatty nature. Some carbonic acid is present. The perspiration is alkaline, but when it is mixed with the sebaceous secretion may be acid.

Usually the perspiration is secreted in small quantity, and then evaporates into the air from the pores of the ducts. Such perspiration is called **insensible perspiration**, because it is not evident to the senses. In hot weather, or in consequence of exertion, the perspiration is poured out faster than it can evaporate and collects in drops. Such perspiration is called **sensible perspiration.** As the perspiration evaporates, water is changed from the liquid to the gaseous condition. In this change heat is absorbed by the water, and the surface from which the evaporation takes place is cooled by the heat thus taken from it. By the perspiration a large quantity of heat is in this way lost from the body. Some heat is also lost by radiation, and some by conduction or contact with colder bodies, but the heat absorbed by the evaporation of the sweat is the most important means of loss. The skin is a source of loss to the body of water, of heat, and of a small quantity of carbonic acid. The amount of water lost varies very greatly, but is usually nearly a pint in twenty-four hours. The amount of sweat secreted, and so of heat and water lost, depends on many circumstances. The activity of the sweat glands, like that of other glands, such as the salivary, is influenced by the nervous system. The sweat glands are supplied by nerves, and certain nervous impulses passing from the brain or spinal cord along these nerves cause the glands to pour out sweat abundantly. Usually, not always, the activity of the glands is assisted by a greater flow of blood to the skin brought about also by the nervous system through the vaso-motor nerves. The two usually go hand in hand; an emotion of shame which leads to blushing leads also to profuse perspiration of the face. But an increased flow of blood to the skin is not the cause of sweating, and, indeed, is not necessary for sweating; in what are called "cold sweats" the glands secrete freely though the supply of blood to the skin is very small. In hot weather the blood-vessels of the skin are dilated, and so it receives more blood, and at the same time the secretion of sweat is more active. The object of the increased perspiration is to remove heat from the body, so as to prevent the body from becoming hotter than usual. In cold weather the vessels of the skin are constricted, and so it receives less blood, and at the same time the secretion of sweat, and thereby the loss of heat, is reduced.

Nails.—A nail consists of epidermis and is formed by the outer or corneous cells, instead of being shed as in other parts

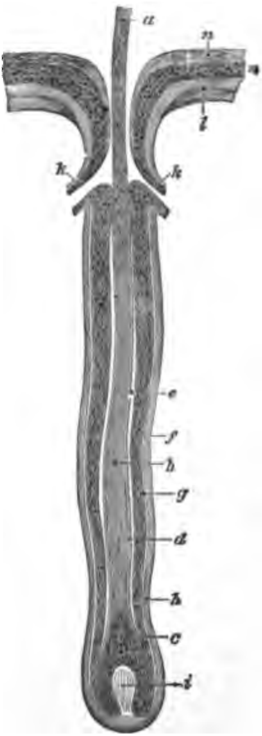


FIG. 79.—A hair in its follicle.

a, shaft of hair above the skin; *b*, the hair in its follicle; *c*, newest portion of the hair growing on the papilla *i*; *d*, cuticle of hair; *e*, cavity of hair follicle; *f*, epidermis of follicle corresponding to *m*, the epidermis at the surface; *g*, division between dermis and epidermis; *h*, dermis of follicle corresponding to dermis, *l*, near the surface; *k*, mouths of sebaceous glands; *n*, horny epidermis at surface.

of the skin, becoming massed together to form a stout horny plate. Underneath the hind part of the nail, at what is called the "bed of the nail," is a very vascular dermis, thrown up into ridges bearing papillæ; from this bed the horny plate of the nail grows. The cells of the deeper, softer layers of the epidermis, just over the dermis of the bed, multiply rapidly, and the cells so formed are thrust forward and become horny and compressed together as new ones are formed behind.

Hairs.—A hair is composed of horny cells, and is formed from the epidermis. It lies in a deep pit, called the **hair follicle**, from the bottom of which it springs. The wall of the hair follicle which passes deep into the skin, is formed of dermis, lined throughout by epidermis. This epidermis forms the sheath of the root of the hair. At the bottom of the pit the dermis rises up into a vascular papilla, and it is by the multiplication of the cells of the epidermis immediately over the papilla that the hair grows. As new cells are formed the older ones, which join together and become corneous, are thrust outwards, and so the shaft of the hair is formed. The shaft of a fully-formed hair consists of a pith or medulla, loose in texture, enclosed by a cortex formed of united, dry, horny cells, which is covered by a cuticle consisting of overlapping scales.

CHAPTER XVI

ANIMAL HEAT

The Temperature of the Body. — The body of a man is usually warmer than the things around him. Moreover, it is as warm on a hot day as on a cold day; the temperature is always the same, being about 98° Fahrenheit (37° Centigrade). This may be ascertained by placing a thermometer in the armpit or in the mouth for a few minutes.

Loss of Heat. — The body is constantly losing heat. Heat is lost, as we have just seen, from the skin by the evaporation of the sweat, by radiation, and by conduction. A considerable amount is also lost by the breath in warming the air expired, and a very little also is lost in warming the urine and the fæces leaving the body. To make up for the heat lost heat must be produced in the body, and seeing that the temperature of the body does not change, the amount produced and the amount lost must be equal to each other.

Source of Heat. — The living tissues are constantly undergoing oxidation, and the complex substances of which they are composed are breaking up into simpler substances, of which the chief are carbonic acid, water, and urea. Heat is formed by this oxidation just as it is formed by the oxidation of coal, which takes place when coal is burnt, for the complex substances of the coal break up in the same way into simpler substances. The heat of the body is due then to the oxidation of the tissues. Some of the tissues are oxidising faster than others, and so produce more heat in the same time. The muscles, forming, as they do, so large a portion of the tissues of the body, contribute most of the heat. Next to them in importance come the large solid organs, such as the liver and brain, but all the living tissues produce some heat, and they are always producing it. When a tissue is in activity, as, for instance, when a muscle is contracting or a gland is secreting, it produces more heat than when it is at rest. When a man is doing work his muscular tissues are oxidising faster, and more heat is produced.

When a man is neither gaining nor losing weight, the energy he gives out daily must come ultimately from the substances he is taking in. If we take the food a man eats in a day we can determine experimentally the amount of energy in the form of heat which this can give out when it is oxidised to the same substances as those into which it would be changed if it were built up into tissues and then oxidised in the body, and we can compare this amount with the amount of energy which the man produces in the day. The energy which the oxidation of the food outside the body produces is all heat; the energy which the man produces inside his body leaves him partly as heat, partly as work done. About one-sixth of the energy produced by oxidation in the body is used to do work, and five-sixths appear as heat. When we make this comparison we find that the amount of heat which results from the oxidation of the daily food outside the body does correspond to the heat (together with that portion of the energy which is used to do work) which the man produces with it in the day. The various food-stuffs vary in the amount of heat they produce when oxidised, and this largely depends on their composition. A given weight of fat will produce twice as much heat as the same weight of carbohydrates or of proteids. This is one reason why much fat is found by man more acceptable and desirable as food in cold climates than in warm climates. The fat must, however, be absorbed, assimilated, built up into tissue before it is oxidised in the body, so that it is no use taking a large amount of fat in order to produce much heat unless this can be digested and assimilated.

Distribution of Heat. — The circulation of the blood distributes the heat, and keeps the temperature very nearly the same throughout the body. When the blood is passing through an organ which is at the time producing much heat, such as a contracting muscle, it leaves the organ warmer than when it entered it, and then circulating through the body distributes this extra heat, and so tends to keep the temperature of all parts the same. The skin is a little colder than the internal organs, and the blood passing through the skin gives up some of its heat, which is lost from the body, and the blood thus cooled is warmed again as it is subsequently distributed through the various organs.

Regulation of Heat. — If the temperature of a man doing active work is taken with a thermometer it will be found to be the same as when he is at rest. The man is producing a great deal more heat by the activity of his muscles, but he does not become any hotter. He must therefore be losing more heat to make up for the increased production. When more heat than usual is formed, more blood is sent to the skin and so more heat is lost. The increased amount of blood sent to the skin favours an increased perspiration, and this leads to the increased loss of heat. A man feels warmer when he is working because the skin is warmer, on account of the greater quantity of blood sent to it, since we form our judgment of the warmth of the body from the temperature of the skin. We feel warm when the skin is warm, and cold when the skin is cold. The temperature of the body, then, is regulated by means of the skin, so that if the production of heat varies the loss varies hand in hand with it. On a cold day the loss of heat from the body would be much greater and would go on much faster than on a hot day if the blood-supply to the skin was always the same, the radiation to the cold things around being much greater. But, as we have seen, cold causes the blood-vessels of the skin to constrict, and thus diminishes the blood-supply and at the same time checks the perspiration, so that the loss of heat is diminished. On a hot day the loss of heat from the body would be but little if it were not for the increased perspiration, for the radiation to the warm things around may be but little, or there may be none. A man can enter a hot chamber or oven where the air is very much hotter than he is without his body being raised in temperature; this is due to the profuse perspiration set up. Thus when the temperature of the air around varies, the loss of heat is still kept very nearly the same by the regulation of the supply of blood to the skin and of the perspiration. In cold weather, however, a trifle more heat is lost than in hot weather, but this is made up for by a slight increase of production, so that the temperature of the body does not change. Cold slightly increases the production of heat, while warmth slightly diminishes it; so that the body temperature is kept constant not only by regulating the amount of loss, but also by regulating to a small extent the amount of production of heat. This regulation is carried out by the nervous system determining on the one hand the loss by governing the supply of blood to the skin and the action of the sweat glands, and on the other hand the production by diminishing or increasing the oxidation of the tissues. In a cold-blooded animal this regulation does not occur, so that the temperature of a frog or a snake falls in winter and rises in summer. The cold of winter renders the cold-blooded animal torpid, while the warmth of summer leads to active movements and rapid oxidation.

CHAPTER XVII

THE NERVOUS SYSTEM

THE brain and the spinal cord with the nerves proceeding from them constitute the nervous system of the body. The brain and spinal cord being the central organs form, taken together, the central nervous system.

Nerves are afferent or efferent. — Nerves carry impulses either to the central nervous system, being then called afferent nerves, or from it, being then called efferent nerves. We have already met with examples of these two classes of nerves. The nerves which carry to the central nervous system impulses from the skin or from the organs of the special senses, such as the eye or the ear, are afferent nerves, and, since these impulses arouse in us the sensations of touch, sight, or hearing, are sensory nerves. The nerves which carry impulses from the central nervous system to the muscles are efferent nerves, and, if the impulses are such as to cause muscles to contract, are motor nerves.

Structure of Nerves. — If a piece of nerve, such as may be taken from a limb of a rabbit, be frayed out at its end with a needle, it will be seen to consist of a number of fine fibres, the **nerve fibres**. These separate fibres, held together by a little fine connective tissue partly lying between them and partly wrapping round them, make up the nerve. The nerve fibres themselves vary much in size, the breadth of a medium-sized one being $\frac{1}{4000}$th of an inch, that is about $\frac{1}{10}$th the diameter of a striated muscle fibre. A nerve fibre consists of a central strand of soft semi-solid protoplasmic substance called the neuraxis or **axis cylinder**. This is covered by two sheaths. The inner sheath, the one next to the axis cylinder, is formed of a peculiar substance of a fatty nature, and is called the **medullary sheath** or medulla. Covering this is the outer sheath, a thin and delicate membrane, called the **neurilemma**. The axis cylinder in the centre of each fibre is a

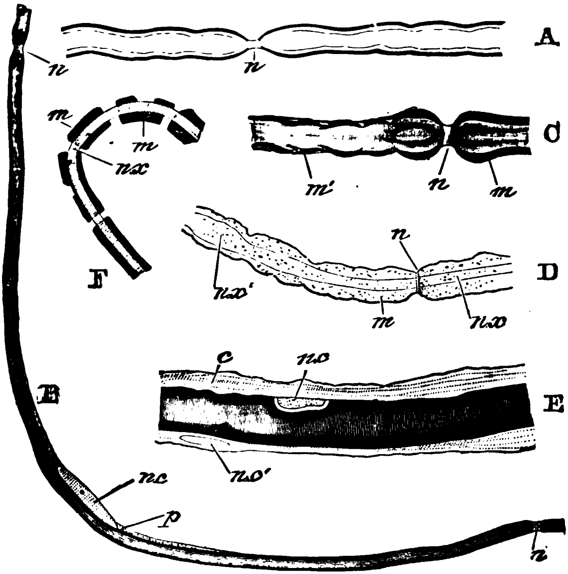


FIG. 80. — To illustrate the structure of nerve fibres.

A. — Nerve fibre examined fresh. *n*, node.
B. — Nerve fibre with neuraxis shaded, and medulla represented by dark lines. *n.c*, nucleus; *p*, granular cell substance near the nucleus.
C. — More highly magnified. *m*, medulla; *n*, node.
D. — Nerve treated with reagents to show the neuraxis, *n.x*, surrounded by medulla, *m*.
E. — Nerve treated with reagents to show *n.c*, nucleus with fine line over it representing the neurilemma, and outside this fine connective tissue *c*; *n.c'*, nucleus lying in the fine connective tissue.
F. — Nerve fibre deprived of its neurilemma showing medulla broken up into fragments, *m*, surrounding the neuraxis, *n.x*.

continuous strand, which generally extends all the way from the central nervous system to the ending of the nerve fibre in the muscle, or skin, or sense organ, as the case may be.

The neurilemma also is continuous throughout the length of the fibre. The medullary sheath, on the other hand, is broken here and there along the length of the fibre at intervals of about $\frac{1}{25}$th of an inch. These breakings are called nodes. Between each two nodes an oval nucleus can generally be found lying just underneath the neurilemma.

In some nerve fibres there is no medullary sheath, the neurilemma alone covering the axis cylinder. These are called **non-medullated** nerve fibres. They are grey in appearance, while the ordinary **medullated** nerve fibres are white.

Nerve Cells. — On some nerves, usually not far from their origin from the central nervous system, or near their ending in the various organs, there is situated a small knot-like swelling. Such an enlargement is called **a ganglion.** When examined microscopically the ganglion shows, intermingled with the nerve fibres, or lying round them, a number of cells, called nerve cells or **ganglion cells.** The ganglion cells vary much in size in different ganglia, but they are often about $\frac{1}{500}$th of an inch in diameter. The cell substance contains a large round nucleus. Some nerve cells are round, others pear-shaped or spindle-shaped, and some are very irregular in outline. They all give off one or more processes, and one of these is a strand which becomes continuous with the axis cylinder of a nerve fibre. The axis cylinders of all nerve fibres are connected in some place or another with at least one nerve cell.

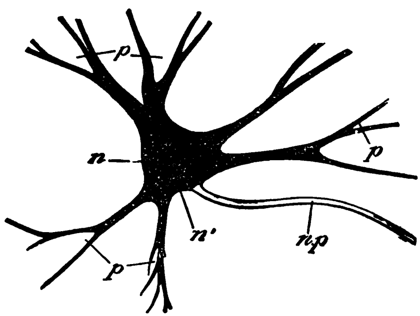


FIG. 81. — A large nerve cell from the anterior horn of the cord spinal.

n, nucleus; *n'*, small body, called the nucleolus, inside the nucleus; *p*, branched processes; *n.p*, unbranched process continued into the neuraxis of a motor nerve fibre.

These then are the elements of nervous tissue as seen in nerves and ganglia: medullated nerve fibres, non-medullated nerve fibres, and nerve cells; and of these elements the brain and spinal cord are made up.

The Membranes of the Brain and Spinal Cord. — The brain is protected by the bones which form the walls of the

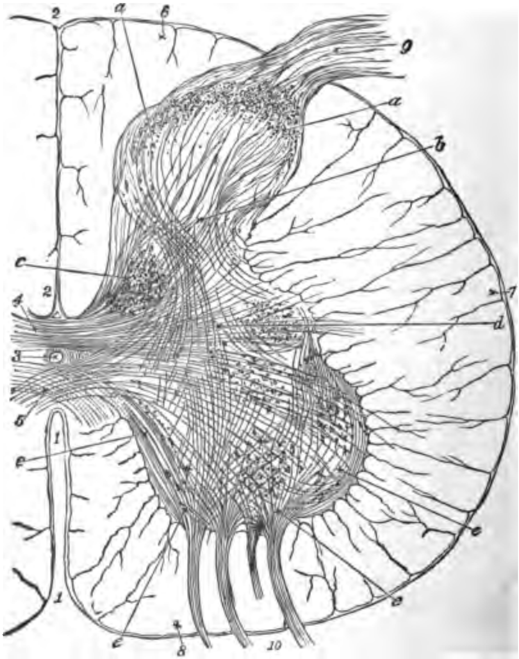


FIG. 82. — Transverse section of one half of the spinal cord in the lumbar region.

1, anterior fissure; 2, posterior fissure; 3, central canal; 4, 5, bridges connecting the grey matter in the two halves of the cord; 6, posterior column of white matter; 7, lateral column; 8, anterior column; 9, posterior root; 10, anterior root. *a*, Posterior horn of grey matter; *e*, anterior horn; blood-vessels are represented passing in from the pia mater covering the cord.

cavity of the cranium, and the spinal cord is protected by the vertebræ which form the walls of the vertebral canal in which the spinal cord lies. The bony walls of these cavities are lined by a tough fibrous membrane, which serves as the inside periosteum of the bones, and receives the special name of **dura mater**. The brain and spinal cord themselves are closely covered by a delicate, very vascular membrane, called the **pia mater**, from which they receive blood-vessels. Between the pia mater and the dura mater is a space containing a little lymph-like fluid, and some loose connective tissue attached partly to one and partly to the other membrane. This loose connective tissue forms a third membrane. It is called the **arachnoid membrane**.

The Spinal Cord. — The spinal cord is a column of soft substance extending from the brain downwards along the spinal canal to, in man, about the level of the second lumbar vertebra, where it tapers off into a filament. It is about 18 inches long in a man of average height, and about half an inch across. Running along the front of the cord is a deep groove called the **anterior fissure**, and along the back of the cord another deep cleft called the **posterior fissure**. The two fissures extend into the cord so far that they nearly meet, leaving only a narrow bridge of tissue connecting the two halves. In the centre of this bridge of tissue is a small canal, called the **central canal**, which runs along the middle of the cord. Connective tissue from the pia mater passes into the fissures, carrying in with it blood-vessels which, like other vessels from the pia mater at the surface of the cord, pass into the substance of the cord, and so supply it with blood.

If the spinal cord be cut across, the cord will be seen to be composed partly of white-looking substance lying on the outside, and partly of grey-looking substance lying on the inside. In each half of the cord, on each side of the fissures, the grey matter and the white matter are correspondingly placed so that the appearance of one half is exactly like that of the other. The grey matter in each half of the cord is somewhat in the form of a crescent with rounded horns, one horn being directed towards the front, and the other towards the back of the cord. These are the **anterior horn** and the **posterior horn** of grey matter. The white matter lies all round the crescent of grey matter except where the crescent in one half is connected, as it is, by grey matter to the crescent in the other half.

The Spinal Nerves. — From the spinal cord, at intervals along its length, nerves, called the **spinal nerves**, are given off in pairs. There are thirty-one pairs of spinal nerves. The two nerves of a pair arise at the same level, one from each side of the cord. Each nerve springs by two roots, one, the anterior root, from the front part, and the other, the posterior root, from the hinder part of its half of the cord. The two roots divide the white matter of each half of the cord into three portions, called, according to their position, the **anterior**, the **lateral**, and the **posterior columns** of the white matter. The anterior and posterior roots soon unite to form the nerve trunk, which then passes out of the spinal canal between the arch of one vertebra and that of the next to be distributed to certain muscles and to a certain part

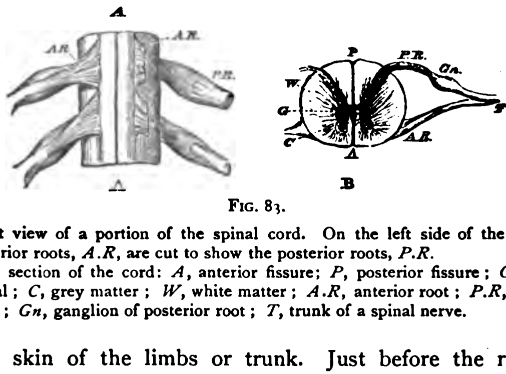


FIG. 83.

A, Front view of a portion of the spinal cord. On the left side of the cord the anterior roots, *A.R*, are cut to show the posterior roots, *P.R*.

B, Cross section of the cord: *A*, anterior fissure; *P*, posterior fissure; *G*, central canal; *C*, grey matter; *W*, white matter; *A.R*, anterior root; *P.R*, posterior root; *Gn*, ganglion of posterior root; *T*, trunk of a spinal nerve.

of the skin of the limbs or trunk. Just before the roots of each nerve join there is a knot-like enlargement on the posterior root. This is the **ganglion of the posterior root.** The nerve cells of these ganglia give off one process only, which by a T-shaped junction becomes continuous with a nerve fibre passing through the ganglion.

Nature of the White and Grey Matter and Origin of the Nerve Roots.—The white matter of the spinal cord consists, with a very little intermingled connective tissue, entirely of nerve fibres, the majority of which run along the length of the cord. In the grey matter there are a number of similar but generally fine white medullated nerve fibres; these, however, run in various directions. There are also a large number of grey non-medullated nerve fibres, and in addition numerous nerve cells. The nerve cells vary in size and shape; those in the anterior horn are the largest, being about $\frac{1}{250}$th of an inch in diameter. Each of these contains a large round nucleus and gives off a number of fine processes branching out in various directions, and in addition a single large unbranched process which proceeds outwards from the grey matter of the anterior horn through the white matter into the anterior root of one of the spinal nerves. The single process is continuous with, and in fact forms the axis cylinder of, a nerve fibre of the anterior root of the nerve. In this way most of the nerve fibres of the anterior root derive their axis cylinders

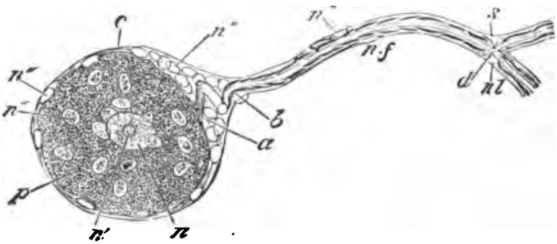


FIG. 84.—A nerve cell from a ganglion of the posterior root of a spinal nerve.

p, the cell substance; *n*, nucleus; *n'*, its nucleolus; *c*, the connective tissue capsule of the cells; *n''*, nuclei of the capsule; *n.f*, nerve fibre dividing into two at *d*; *nl*, neurilemma; *s*, sheath.

from the single unbranched processes of nerve cells in the anterior horn. So that the anterior root springs largely from the grey matter of the anterior horn. Similarly some of the fibres of the posterior root pass into the grey matter of the posterior horn and become connected with the nerve cells of the grey matter, though in a different way. The nerve cells of the posterior horn, smaller than those of the anterior horn, are like them in giving off a number of fine processes, but differ from them in having no axis cylinder process. While the fibres of the anterior root may be considered as axis cylinder processes of the cells of the anterior horn, the fibres of the posterior root may be considered as axis cylinder processes of the cells of the ganglion of the posterior root, and therefore end in the grey matter of the cord in a different way. The great majority of the fibres of the posterior roots do not go into the grey matter of the posterior horns at the level where they spring, but run up the cord in the posterior columns of white matter, and go into the grey matter of the cord higher up, or even pass to the spinal bulb.

Function of the Nerve Roots.—Some of the nerve fibres in a spinal nerve trunk carry impulses from the skin to the spinal cord, and some carry impulses from the spinal cord to the muscles; that is, some of the fibres are sensory and some are motor. These two kinds of fibres run together down the nerve trunk, parting company at length to go to the particular portion of skin and the particular muscles supplied by that nerve. As the nerve trunk is traced back to the spinal cord, it is found that at the junction of the two roots the sensory and motor fibres are sorted out, and that all the sensory fibres pass into the cord by the posterior root, and all the motor fibres by the anterior root. The posterior is therefore called the **sensory root** and the anterior the **motor root** of the spinal nerve. If the posterior root of a spinal nerve has been severely injured or cut across, the prick of a pin or the heat of a burning coal applied to that portion of the skin to which the nerve goes is not felt at all. The connection of the sensory fibres of the nerve with the spinal cord has been broken; hence no sensory nervous impulses can reach the spinal cord, and so the brain, from the nerve. Motor impulses, which pass from the spinal cord along the anterior root, can be transmitted just as well as before the posterior root was cut, and lead as before to the contraction of the muscles to which the nerve goes. If, on the other hand, the anterior root and not the posterior be injured or cut across, these motor impulses cannot pass and the corresponding muscles cannot be set in action; they are said to be paralysed. In this case, however, sensory impulses can pass from the skin to the cord, and so to the brain, as well as before; pain can be felt in the part of the body to which the nerve goes, but no movement can be produced there. What has just been said of sensory and motor fibres applies also to all afferent and efferent fibres.

Functions of the Spinal Cord.—When a man "breaks his back" he receives some injury to the vertebral column, which cuts across the spinal cord, or so damages it that a certain length of it is more or less completely severed from, or at least can no longer conduct impulses from the brain. If the injury is in the middle of the back, the man will be unable to move his legs or any part of his body which is supplied by nerves which arise from the cord below the level of the injury; all parts below the level of the injury will be "paralysed." He will also be unable to feel the prick of a pin or a hot coal applied to his legs or to any part below the injury; that is, there is a loss of sensation in all parts below. It is one of the functions of the spinal cord to transmit up to the brain the impulses it receives by the sensory nerves; when the cord is severed from the brain these impulses can no longer pass upwards. Again, when a man wishes to move a leg or other part, impulses are started in the brain and transmitted from the brain downwards along the spinal cord, and cause motor impulses to pass out along the anterior roots of the spinal nerves going to the appropriate muscles; when the cord is severed from the brain these impulses can no longer pass downwards. A man whose spinal cord is injured at the level of the first rib still goes on breathing, but by means of the diaphragm only, since impulses from the respiratory centre of the spinal bulb cannot pass down to the intercostal nerves, which are branches of the spinal nerves of the thoracic region below the injury, but they still can pass to the diaphragm by the phrenic nerves, which branch off from the spinal nerves by the cervical region above the injury.

Reflex Action.—If the soles of the feet of a man whose spinal cord is injured anywhere above the sacral region be tickled, it often happens that his legs will be suddenly drawn up, though the man cannot feel the tickling, and cannot of his own will draw up his legs. How is this brought about? The tickling causes sensory impulses to pass up the sensory fibres of the nerves along their posterior roots into the spinal cord. These impulses so act on the grey matter of the cord that they cause new impulses, motor impulses, to arise, and these pass from the grey matter of the anterior horn by the anterior roots into the nerves going to the muscles of the leg, and so the muscles contract. These movements are produced without the action of the will or brain, for all connection with the brain has been destroyed by the injury. A movement produced by the spinal cord or brain without the action of the will, and in consequence of sensory impulses brought to it, is said to be produced by **reflex action.** Reflex actions, though they are observed in any animal and in ourselves, can best be studied in a cold-blooded animal, such as a frog, which has been deprived of its brain by cutting off its head; such an animal remains still and motionless, no sign of movement, except the beating of the heart, being seen so long as it is left undisturbed. It can feel nothing, cannot move of its own will, and will remain lying on its belly till it dries up; yet if the toe is pinched the leg will be drawn away. If a small bit of blotting paper moistened with acid, even if the acid is very dilute, be placed on one of the legs or on the flank, one leg or both will be used to rub it away. The acid irritating the skin, however slightly, causes sensory impulses to pass from the spot to the spinal cord, and motor impulses are then sent out from the grey matter of the cord to those muscles which can move the leg in such a way as to rub away the acid. In order to remove the acid the foot has not to be jerked up aimlessly, but has to be brought up with precision to where the acid is, and then has to rub it away. To perform these movements many different muscles have to be brought into action in proper order and with proper amount of force. So that a few simple sensory impulses passing up, it may be along a single nerve, to the spinal cord lead to the outflow of a large number of carefully-adjusted motor impulses passing out along several nerves. Thus we see that the spinal cord, in addition to being a path for the transmission of impulses to and from the brain, is able to originate complicated and delicate movements; but this only in response to the impulse of an afferent nerve.

A large number of the movements we perform are brought about by reflex action. If a strong light is flashed across the eyes they are instantly closed; if the hand comes in contact with a hot body it is at once drawn away; if a sudden sound is heard we start: these are instances of reflex actions, the movements being produced by the central nervous system without the action of the will, and in consequence of sensory impulses reaching it. Some of these are, moreover, instances of reflex action carried out not by the spinal cord alone, but by the intervention also of the brain, and in the first of the instances given, of the brain exclusively. Many movements of ordinary life which are started by the will, and therefore voluntary, are often continued reflexly. Thus we can go on walking without thinking about it, every step being properly performed, the necessary muscles contracting because they receive impulses from the central nervous system, regulated in accordance with sensory impulses received by the central nervous system, from the eye, or the ear, or due to the contact of the legs themselves with the ground. Again, mainly involuntary movements, such as those of respiration, are carried out or modified by reflex action either of the spinal cord or of some part of the brain.

The Brain

The brain is a large organ consisting of several parts. The lowest part, called the **spinal bulb** or **medulla oblongata,** is continuous with the spinal cord, and is somewhat like it in structure, but is larger in diameter, gradually increasing in width from the spinal cord upwards. The bulb in its natural position gradually bends forwards, so that the brain lies rather in a fore-and-aft direction than in an up-and-down direction like the spinal cord. Springing from the sides of the upper part of the bulb is a large mass which lies on the dorsal or hinder side of the bulb, and largely overlaps it downwards. This is called the **cerebellum**; its surface is closely folded or plaited. The cerebellum is connected to the bulb not only by nervous tissue passing into it from the bulb on each side, but also by a large bridge of tissue, consisting mostly of bundles of nerve fibres passing from one side to the other across the front of the upper part of the bulb. This bridge of tissue is called the **pons**. Some of the bundles of nerve fibres which make up the white matter of the spinal bulb pass from the bulb into the cerebellum, while othe bundles go straight on past the pons, forwards and upwards, connecting the bulb with the parts of the brain in front. Just above the pons these bundles of fibres appear as two columns, called the **crura cerebri**, one on each side at the base or lower side of the brain. These columns diverge from one another as they pass forwards to the two largest masses of the brain, the **cerebral hemispheres**. On the upper side of the crura cerebri the brain substance is raised up into two pairs of rounded masses called the **corpora quadrigemina**. In front of these are

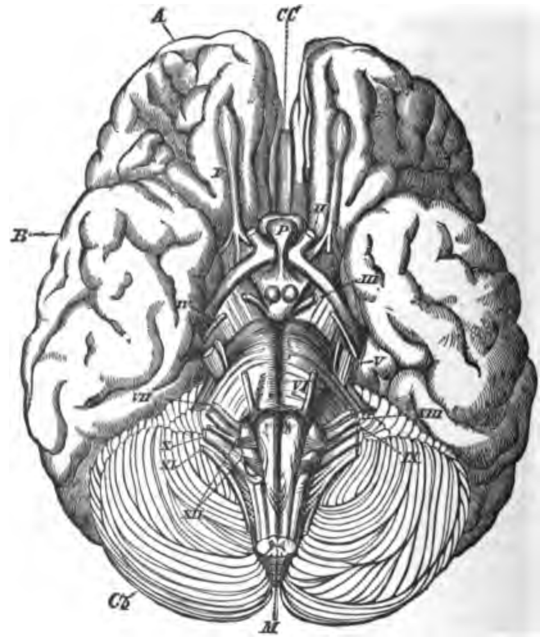


FIG. 85. — The base of the brain.

A, the anterior or frontal lobe of the right cerebral hemisphere; *B*, the lateral or temporal lobe; *Cb*, the cerebellum; *M*, medulla oblongata; I. to XII., the twelve cranial nerves; *CC*, part connecting the two hemispheres together, *P*, is placed just in front of the crossing or chiasma of the optic nerves.

two larger masses, one on either side, called the **optic thalami**, into or past which most of the fibres of the crura cerebri go. The cerebral hemispheres are two large masses, one on each side, separate from each other, except where they are joined together by a flattened band of nerve fibres running across from one hemisphere to the other. They are connected to the other parts of the brain chiefly by the crura cerebri, but also by the optic thalami. Towards the under surface or base of the hemisphere lie special structures, one on each side;

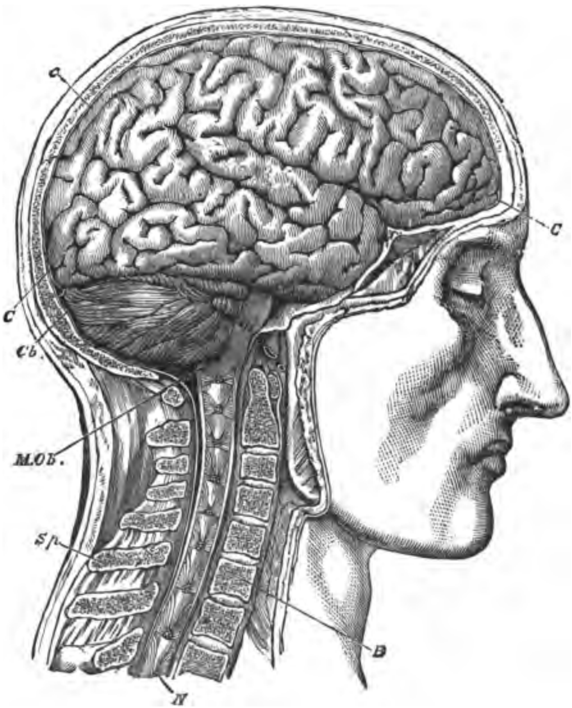


FIG. 86. — Side view of the brain and upper part of the spinal cord.

C, the convoluted surface of the right cerebral hemisphere; *Cb*, cerebellum; *M.Ob*, medulla oblongata; *N*, spinal cord with spinal nerves; *B*, the bodies, and *Sp*, the spines of the vertebræ.

these are called the two **corpora striata**. The surface of the cerebral hemispheres is thrown into folds called convolutions, with fissures more or less deep between them; this gives it a very characteristic appearance.

The brain is composed of white and grey matter of the same nature as the white and grey matter of the spinal cord. The arrangement of the white and grey matter varies in different parts of the brain, but is always the same in corresponding parts on the two sides. In the spinal bulb the arrangement is like the arrangement in the cord, except that there is more grey matter relatively to the white. In each cerebral hemisphere the grey matter forms a layer at the surface called the cortex, and the white matter which this layer covers consists chiefly of nerve fibres which are passing inwards from this surface grey matter all round. These fibres are largely collected into bundles at the lowest part of the hemisphere, forming the crura cerebri and other connections of the hemispheres with other parts of the brain.

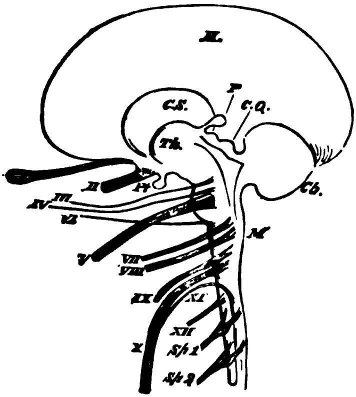


FIG. 87.—Diagram showing the origin of the cranial nerves on the left side.

H, cerebral hemisphere; *C.S*, corpus striatum; *Th*, optic thalamus; *C.Q*, corpora quadrigemina; *Cb*, cerebellum; *M*, medulla oblongata; I. to XII., the cranial nerves; *Sp.* 1, *Sp.* 2, the first and second spinal nerves.

The Cranial Nerves.—Twelve pairs of nerves, called the cranial nerves, arise from the brain, one nerve of each pair arising from one side, and the other from the corresponding part on the other side of the brain.

The first pair. The olfactory nerve, or nerve of smell, arises from the front of each cerebral hemisphere.

The second pair. The optic nerve, or nerve of sight.

The third pair. The motor nerve going to four of the muscles which move the eyeball.

The fourth pair. Motor nerve, going to one of the muscles (the superior oblique muscle) which moves the eyeball.

The fifth pair: called the trigeminal nerve, because it divides into three main divisions. It arises by two roots, a motor root and a sensory root, and so resembles a spinal nerve, and the sensory root, like that of a spinal nerve, possesses a ganglion. It is the motor nerve for the muscles of mastication and the sensory nerve for the mouth and tongue.

The sixth pair. Motor nerve, going to one of the muscles (the external rectus muscle) which moves the eyeball.

The seventh pair. Motor nerve, going to the muscles of the face, mouth, and lips, and therefore called the facial. These muscles give rise to expression by drawing upon and moving the skin of the face.

The eighth pair. The auditory nerve, or nerve of hearing.

The ninth pair. The glosso-pharyngeal nerve, like the fifth, partly sensory and partly motor. The main sensory part goes to the tongue, and is the chief nerve of taste. The motor part supplies the muscles of the pharynx.

The tenth pair. The vagus or pneumogastric nerve. A large nerve which passes from the head down the neck to the thorax and abdomen. It is partly motor and partly sensory. It gives branches to the larynx, the lungs, the heart, the œsophagus, the stomach, intestine, and the liver.

The eleventh pair. The spinal accessory nerve. Motor nerve arising by many roots from the upper part of the spinal cord and then running upwards, gaining more fibres from the bulb before it passes out, as it does, with the vagus nerve. It goes to certain muscles of the neck.

The twelfth pair. The hypoglossal nerve. Motor nerve for the muscles of the tongue.

Of the cranial nerves the last six arise from the spinal bulb, and all of the other six except the first two arise from the parts of the brain just in front of the bulb.

The first two cranial nerves are not nerves like the others, but in reality processes of the brain.

The Functions of the Spinal Bulb.—The spinal bulb, besides giving rise to so many of the cranial nerves, is in many other ways a very important part of the brain. We have seen that the respiratory movements of the chest are not only regulated by, but originated by nervous impulses arising in a part of the bulb called the respiratory centre, and injury to the bulb causes respiration to stop, and so produces death. We have also seen that the beat of the heart is regulated by nervous impulses sent from the bulb, and that the size of the small arteries is regulated by impulses sent along the vaso-motor nerves from a part of the spinal bulb called the vaso-motor centre. There are, in addition to these, other parts of the bulb which govern the act of swallowing, the secretion of saliva, and other processes. In addition to being the seat of these important regulating functions, the bulb forms the path through which all impulses from the cerebral hemispheres and other parts of the brain must pass on their way to the spinal cord and spinal nerves, and similarly the path for all impulses from the spinal nerves and spinal cord to the cerebral hemispheres. It is a very remarkable fact that the nerve fibres which carry motor impulses descending from the brain to the spinal cord cross over rather suddenly from one side to the other on their way through the spinal bulb. So that the fibres which carry motor impulses from the right cerebral hemisphere, having passed downwards in the crus cerebri on the right side to the bulb, cross over in the bulb to the left side and then continue downwards in the white matter of the left side of the cord. Certain injuries to one cerebral hemisphere, for instance, the right, such as the bursting of a blood-vessel in it, cause paralysis of the opposite side of the body, namely, in this case, of the left arm, left leg, and left side of the face and trunk.

In a similar way sensory impulses received from one side, for instance, the left side of the body, are carried by fibres in the white matter of the same, the left side of the spinal cord, which cross over partly in the spinal cord itself, partly in the bulb, to the other, the right side, and so reach the opposite, the right cerebral hemisphere, where they give rise to definite sensations. So it is that after certain injuries to the right cerebral hemisphere impulses starting from the skin on the left side of the body do not give rise to sensations in the brain. The injury to one of the hemispheres causes both paralysis, or loss of voluntary movement, and loss of sensation on the opposite side of the body.

Functions of the Cerebral Hemispheres.—The cerebral hemispheres are the seat of the perceptions, of the intelligence, and of the will. A frog which has been deprived of the cerebral hemispheres only, the other parts of the brain having been left, is like a frog deprived of its whole brain in so far as it feels nothing and performs no voluntary movements, but the two differ in important respects. The frog, the whole of the brain of which has been removed, lies flat and flaccid in whatever position it is placed and does not breathe. The frog deprived of its cerebral hemispheres only sits up in the attitude of an ordinary frog and goes on breathing. A slight touch causes it to move, so also does a flash of light, provided that the optic nerves have not been injured, and even placing it on its back or in any unusual attitude is a sufficient stimulus to make it move to its natural sitting posture. If it is put into water, it will start swimming, and go on till it gets out of the water, if this is possible, and then it will come to rest and remain at rest till disturbed again. From these observations it is clear that while the cerebral hemispheres are necessary for originating voluntary movements, the other parts of the brain can give rise to complicated and well-balanced movements, movements apparently as perfect as those the ordinary animal can perform, provided that afferent impulses, even slight impulses, are received.

The Sympathetic Nervous System.—The spinal nerves on each side of the body, soon after they pass outside the vertebral column, give off a small short branch which goes to a row of ganglia lying on each side of the front of the vertebral column. Each ganglion is connected by nerve fibres to the ganglia above and below it, and so a chain of ganglia, called the **sympathetic chain**, is formed on each side, extending all the way from the base of the skull to the coccyx. There is in the thoracic and lumbar regions a ganglion of each chain corresponding with great regularity to each spinal nerve, but in the cervical region many of them appear to be missing. From the sympathetic chain on each side nerve fibres pass in great numbers to the viscera of the abdomen and thorax. From them nerves are also given off which pass back into the spinal nerves and others which pass into some of the cranial nerves; these are thus distributed to the blood-vessels of the limbs, trunk, and other parts to which the spinal or cranial nerves go. The sympathetic nerves chiefly carry impulses which govern the muscular tissue of the viscera and the muscular coat of the small arteries of the various tissues. It is through the sympathetic nerves that the tone of the blood-vessels is kept up by the action of the vaso-motor centre in the spinal bulb. It must be clearly understood that the sympathetic derives the impulses which it distributes from the central nervous system; these do not arise in the sympathetic itself. The impulses come out of the spinal cord by the anterior roots of the spinal nerves, and so pass by the short branches, spoken of above, into the sympathetic chains.

Very many of the nerve fibres which run in the branches of the sympathetic chains are non-medullated fibres.

CHAPTER XVIII

SENSATION — TOUCH — TASTE — SMELL

We have seen that afferent impulses reaching the central nervous system may by reflex action give rise in the central nervous system to motor impulses or to other efferent impulses, such as secretory. Many reflex actions take place without our being aware of any afferent impulses. When afferent impulses give rise in us to a feeling by which we are aware something is happening, we speak of it as a **sensation**. Some sensations arise altogether in ourselves and are indefinite, so that we cannot say where in our bodies they arise; such are sensations of fatigue, restlessness, and the like. Other sensations are very definite; we judge them at once to be caused by something around us, or by some influence reaching us from without; such are the five sensations — **touch**, **taste**, **smell**, **hearing**, and **sight**. Besides these five special senses, as they are called, we have as distinct from the sensations of touch proper, that is, of **pressure**, sensations of **temperature**, and in addition the somewhat peculiar sensations which we call sensations of **pain** and those which are called **muscular sensations**.

The five special sensations arise in special parts of the body only; sight and hearing are confined to the eye and the ear; and smell and taste to certain parts of the mucous membrane lining the nose and mouth; and touch, though it is not so restricted as these, arises only in the skin and certain parts of the mucous membrane lining the alimentary and other passages. The particular parts of the body where these sensations arise are called the special sense organs. The skin is the sense organ for touch just as the ear is the sense organ for hearing. The sensory nerves of each sense organ end in a special part of the organ, which is therefore the essential part, and from this the impulses pass along the nerve, while the other parts of the organ protect the essential part, or collect and transmit to it the external agencies which cause the sensation.

Touch. — In some of the papillæ of the dermis a sensory nerve ends in an oval structure consisting mainly of nucleated cells, called a **tactile corpuscle.** In addition to the tactile corpuscles and other structures similar to them, which all lie in the dermis, some exceedingly fine fibrils from the sensory nerves in the dermis can be traced into the deeper layers of the epidermis, ending between, or in connection with, some of the cells of the epidermis. The endings of the sensory nerves, both the tactile corpuscles and the endings in the epidermis, are covered externally by either the whole of the epidermis or, at least, its outer or corneous part, so that there is never any actual contact of the thing we touch with the nerve itself. The proper sense of touch cannot arise by direct contact with the nerve; there must always be intervening the particular epithelial cells in connection with which the nerve ends. When part of the skin is removed by a blister, touching the blistered spot gives rise to a different sensation, pain, and not to the true sense of touch; we cannot tell what kind of surface the thing touching the blistered spot has, whether it is smooth, rough, or jagged, and the like.

The sense of touch is most delicate at the tips of the fingers and on the face and tip of the tongue; it is less delicate in other parts of the body on account of a thicker epidermis and a less plentiful supply of sensory nerve endings. If a pair of blunt-pointed compasses, with the points separated only one-tenth of an inch, be gently applied to the tip of the finger, the two points will be distinctly felt, while if they be applied to the back of the hand or the arm, there will only be a sensation of one point, and indeed the points may be put much farther apart and yet be felt as one only. This shows that touch is far more delicate at the tip of the finger than on the back of the hand or arm. Touch is very delicate at the tip of the tongue; there the compasses will be felt as two points, even when they are as close together as one twenty-fourth of an inch. On the cheek the points are usually still felt as one when they are as much as an inch apart, and on the back of the body even when they are three inches apart. The sense of touch is therefore least delicate on the back.

Temperature Sensations. — Besides the sensation of touch which arises from the contact of a body with or from pressure on the skin, we may have sensations of another kind, sensations of warmth or of cold. In such cases it is the change of temperature of the skin caused by the hot or cold body which gives rise to the sensation. If one hand is cooled by being placed in ice-cold water, and the other hand warmed by being placed in hot water, lukewarm water will then feel warm to one hand and cold to the other. The change of temperature acts on the endings of the sensory nerves. It is only through the peculiar end organs of the nerves that these sensations can be excited by changes in temperature, for cold or heat applied directly to the nerve lead only to pain. The sense of warmth varies in delicacy in different parts of the body. It is delicate on the palms of the hands, and, unlike the sense of touch, particularly so on the cheeks. This is why a washerwoman holds her iron near her cheek to tell if it is too hot.

Muscular Sensations. — If the hand is resting on the table and a weight is placed in the palm, we experience a sensation of touch, we feel the pressure of the weight, and from the amount of this pressure we can, without moving the hand, form an idea of the weight of the body. But we can form a much better judgment as to the weight of the body if instead of keeping the hand still on the table we raise and lower the hand so as to lift the body up and down. We then form our judgment by sensations which are in some way connected with the contraction of the muscles by which the weight is poised, and hence are called muscular sensations.

Taste. — The organ of the sense of taste is the mucous membrane of the mouth, especially that of the tongue and palate. The tongue is composed of a mass of striated muscular fibres, running in various directions, covered by mucous membrane. This mucous membrane consists of an outer epithelium formed like the epidermis of several layers of cells, and beneath this of a vascular connective tissue layer corresponding to the dermis. As in the skin, the dermis is raised up into papillæ, but the papillæ of the tongue are much larger and the epithelium over them follows their outline, so that they project out on the surface.

There are three kinds of papillæ. Over the front and at the sides of the tongue the papillæ, closely packed together, are long and slender, and hence are called **filiform papillæ**. In many animals they are very long and prominent, and the roughness they give to the tongue in such animals as the cat and dog assists these animals in taking up their food. Scattered among the filiform papillæ are others, broad at their summits but narrow at their bases, called **fungiform papillæ**, because they are somewhat mushroom-shaped. The third kind are much larger papillæ, each shaped like a mound with a ditch round it. These are called **circumvallate papillæ**. In man these are found only at the back of the tongue in two rows in the form of a V, pointing backwards. On the circumvallate, and on many of the fungiform papillæ, the epithelial cells at the sides of the papillæ are arranged into special groups called **taste buds**. Each taste bud consists of a number of epithelial

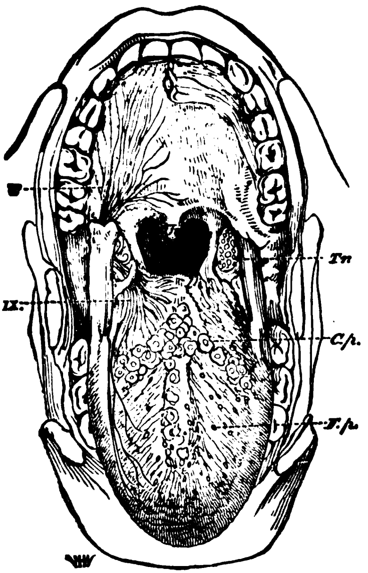


FIG. 88.—The mouth widely open to show the tongue and palate.

Uv, uvula; *Tn*, tonsils; *C.p*, circumvallate papillæ; *F. p*, fungiform papillæ, minute filiform papillæ scattered between them.

On the right side branches of the fifth nerves to the palate, and of the ninth to the tongue are represented.

cells, which lie together somewhat like the leaves in a bud; hence their name. The innermost cells of each bud differ from the other cells in having a delicate process reaching outwards to the surface, so that there is a small cluster of fine processes coming up to the surface out of each bud. To these innermost cells nerve filaments coming from the glosso-pharyngeal or ninth cranial nerve can be traced. A branch of the fifth cranial nerve is also concerned with taste. If some dissolved quinine is taken into the mouth these delicate processes are influenced by the contact of the quinine solution, and cause the epithelial cells of the bud to send impulses along the nerve fibres to the brain, and

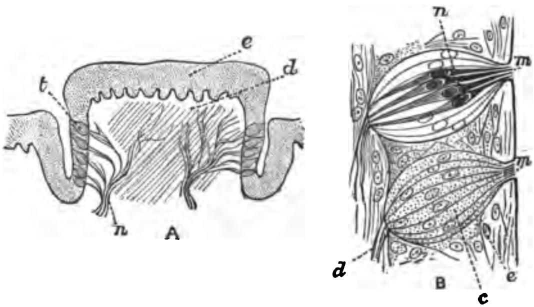


FIG. 89.—Diagram of a circumvallate papilla, and of taste buds.

A, A circumvallate papilla cut across; *e*, epidermis; *d*, dermis; *t*, taste buds; *n*, nerve fibres.

B, Two taste buds; *e*, epidermis; *d*, dermis; *c*, the outer or cover cells shown in the lower bud; *n*, four inner cells with processes; *m*, processes projecting at mouth of buds.

these impulses make us aware of the bitter taste. The mucous membrane of the palate is very similar to that of the tongue, though the papillæ are not so prominent; in it too taste buds occur.

There are four kinds of taste properly so called, namely, the sweet, the bitter, the sour, and the salt. It is with these tastes only that the taste buds just described have to do. But besides tastes proper we have sensations which we call tastes or better "flavours," such as the flavours of meats and drinks, but which are really sensations of smell. The flavour of an onion, for instance, is really the sense of smell excited by odorous particles acting on the nose through the anterior or the posterior nares. This is proved by the fact that if we hold the nose, or if we are suffering from a severe cold which does away for a time with the sense of smell, we "lose our taste," as we say; then we cannot well distinguish the flavour of an onion from that of an apple. But holding the nose will not do away with a taste proper like that of sugar or of hops. True tastes may be mixed with other sensations in addition to those of smell, such as pungent, smarting, tingling, or similar sensations. Our judgment of the flavour of what we eat is formed after taking into account all the sensations which it gives rise to.

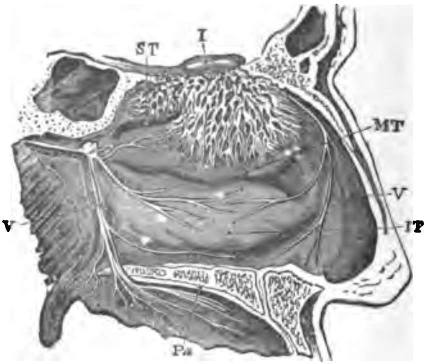


FIG. 90. — The outer wall of the left nasal cavity.
I, the olfactory nerve and its branches; V, branches of fifth nerve; *Pa*, palate; *ST*, *MT*, *IT*, the three turbinal bones covered with mucous membrane.

Smell. — The organ of the sense of smell is the mucous membrane lining the upper part of the cavity of the nose. The nostrils or anterior nares lead into the nasal chambers, which are separated from each other by a median partition. The floor of the nasal chambers is formed by the hard and soft palate, which separate them from the mouth. Each nasal chamber opens behind by the posterior nares into the upper part of the pharynx. The roof of the chambers in its front part between the eyes is formed by a plate of bone, the **cribriform plate**, which separates them from the cranial cavity in which the brain lies. Through this plate of bone, which is perforated by numerous holes, the branches of the olfactory nerves stream from a part of the cerebral hemispheres called the olfactory bulb. Into each nasal chamber three delicate scroll-like bones, called the spongy or turbinal bones, project from the side wall. These bony projections, like the rest of the walls of the cavity, are covered by mucous membrane. The epithelium of the mucous membrane in the lower part of each nasal cavity, including the lowest spongy bone, consists of a single layer of tall ciliated cells, like the epithelial cells of the trachea. This is the respiratory part of the nasal chamber, that is, it is the part along which the air chiefly passes in ordinary breathing through the nose. The upper part of the chambers, including the upper and middle spongy bones, is the olfactory part, and the epithelium here is different. The epithelial cells are in more than one

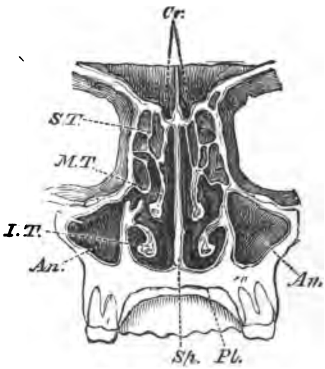


FIG. 91.— A vertical transverse section through the nasal chambers.

Cr, cribriform plate; *Sp*, septum; *Pl*, palate; *An*, chamber of upper jaw-bone; *S.T*, *M.T*, *I.T*, the three turbinal bones.

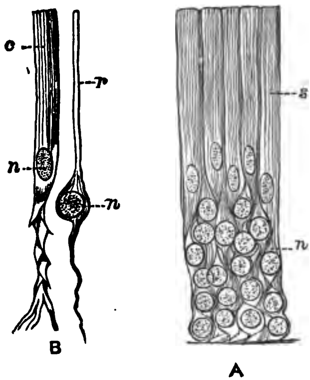


FIG. 92. — Diagram of olfactory epithelium.

A, The epithelial cells, as they naturally lie, close together; *s*, the superficial part; *n*, the deeper, nuclear part.
B, Two cells separated; *c*, a cylindrical cell; *r*, a rod cell; *n*, nuclei.

layer, and have no cilia; many of them are delicate and rod-shaped, and to these latter the branches of the olfactory nerve can be traced.

By sniffing more air is drawn into the upper parts of the nasal chambers than is the case in ordinary inspiration, so that we sniff when we wish to detect a faint smell. Any odorous particles in the air act on the delicate rod-shaped cells, and impulses pass from them along the olfactory nerves to the brain.

CHAPTER XIX

THE EYE AND THE SENSE OF SIGHT

Protection and Movements of the Eyeball. — The eyeball is a completely closed globular organ lying in the bony cavity of the orbit, the walls of which protect it, except in front, where it is guarded by the eyelids. These latter consist of a

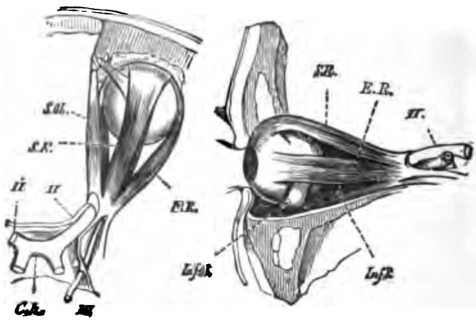


FIG. 93.

A. — The muscles of the right eyeball viewed from above.
B. — The muscles of the left eyeball viewed from the outer side.
S.R, superior rectus; *Inf.R*, inferior rectus; *E.R*, external rectus; *S.Ob*, superior oblique; *Inf.Ob*, inferior oblique; *II*, the optic nerves; *ch*, their crossing or chiasma; *III*, the third cranial nerve.

sheet of dense fibrous connective tissue covered on the outer side by skin, and on the inner side by a membrane with a stratified epithelium, like the epidermis of the skin, but much thinner, called the **conjunctiva**. At the base of the eyelids the conjunctiva passes on to the eyeball, and, firmly attached to it, forms a delicate layer on the front of it. There is thus no break in the continuity of the epidermis; it becomes much thinner and transparent on the front of the eyeball. Lying in the eyelids are striated muscle fibres, placed circularly round the eye. Contraction of these closes the eye. The eye is opened by the action of a muscle which raises the upper lid. Blinking, the sudden closure of the eyes which occurs unconsciously every few seconds, may be a reflex act. The sensory nerve concerned is a branch of the fifth cranial; this carries impulses, due to an irritation, it may be a very slight one, on the surface of the eye, up to the brain, and motor impulses are sent out along the seventh cranial nerve to the muscle fibres of the eyelids.

The eyeball is attached behind by the optic nerve, which is large, and forms, as it were, the stalk of the organ, passing from the brain through a hole at the back of the orbit. Six striated muscles connect the eyeball with the wall of the orbit. Four of these muscles, attached to the back of the orbit around the entrance of the optic nerve, pass straight forward, and are inserted into the front part of the eyeball, just behind what we shall presently describe as the cornea; they are the straight or rectus muscles, and are named the external, internal, superior, and inferior rectus muscles, according to their position. The external rectus muscle turns the eyeball outwards, the internal rectus inwards, the superior rectus upwards, and the inferior rectus downwards. Two other muscles, called oblique muscles, inferior and superior, attached to the sides of the orbit, and pursuing a slanting, or even bent course, the tendon of the superior passing through a pulley, are inserted into the eyeball behind the place of insertion of the straight muscles. By means of the action of one or more, usually of two or more, of these muscles, the superior oblique and inferior rectus usually working together, and the inferior oblique and superior rectus together, the eyeball can be turned in many directions. When we look at an object both eyes are directed to it, and if the object is near, the muscles of both eyes are so balanced as to turn both eyeballs inwards and to keep them steadily directed on the object.

The rest of the cavity of the orbit is occupied by fat and the blood-vessels and nerves connected with the eye and its muscles, and in addition by a small gland on the outer side of the orbit called the **lacrymal gland**. This gland, which is like a simple salivary gland in structure, secretes a watery fluid, which when excessive escapes as tears. Usually the fluid, which is always being formed, after flowing over the eyeball, is collected by two canals, the openings of which are readily seen, one on the edge of each eyelid close to the inner corner of the eye. The two canals soon unite to form the lacrymal duct, one for each eye, which conducts the fluid to the cavity of the nose. In addition to the lacrymal secretion, which keeps the front of the eyeball clean and moist, there is also a thicker fluid formed by small glands situated in the eyelids.

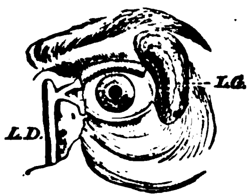


FIG. 94. — Front view of left eye, with eyelid partly removed to show lacrymal gland *L.G*, and lacrymal duct *L.D.*

General Structure of the Eye. — Obtain the eye of a bullock from a butcher. Carefully clear away the fat at the back of the eye so as to see distinctly the optic nerve, of which there will probably be about half an inch left passing into the eyeball. The fat will be surrounded by an almost continuous sheath of muscle which is made up of the six distinct muscles cut across in taking the eye out of the orbit. Hold the eyeball carefully, and very gently squeeze it behind so as to keep the front of it tense. You will see that the eyeball is not a simple round globe, for the extreme front is raised and more strongly curved than the rest, as if it were a piece of a smaller globe put on to a larger one. This front part is called the **cornea**. It is transparent, but appears dark since dark internal structures are seen through it. It is continuous at its edge with the white thick fibrous outer coat of the eyeball, the **sclerotic**. Just beyond the edge of the cornea you will be able to pick up a thin shining membrane attached to the eyeball all round; this is the conjunctiva.

The eye of a man appears black in the centre, with a variously-coloured ring round the centre. In bullocks' eyes the centre is dark grey and is surrounded by a black ring. The ring, variously coloured in ourselves and black in the bullock, is a circular curtain attached to the edge of the cornea all round, leaving in the centre an aperture which appears dark. The curtain is called the **iris**. The aperture is called the **pupil**. The colour of the iris, black, brown, blue, and the like, is due to the varying amount and distribution of granules of black pigment in it.

At the edge of the cornea the iris is continuous all round with a second coat which lines the hinder three-fourths of the eye.

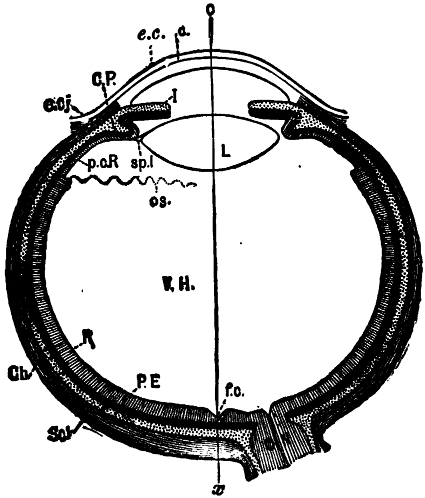


FIG. 95. — Diagram of the eye.

Scl, sclerotic, shaded, continuous with *c*, cornea, not shaded; *e.c*, epithelium of cornea, continuous with *ec.j*, epithelium of conjunctiva; *Ch*, choroid; *C.P*, ciliary process; *I*, iris; *R*, retina; *P.E*, pigmented epithelium between retina and choroid; the retina proper ends at the wavy line *os*, but is continued as a thin layer, *p.c.R*, over the ciliary processes; *L*, lens; *sp.l*, its suspensory ligament; *V.H*, vitreous humour; *f.c*, yellow spot; *O.N*, optic nerve.

This coat is called the **choroid**; it is loosely attached to the inner surface of the sclerotic up to the edge of the cornea, where it leaves the outer coat and juts out across the eye, forming the iris. The choroid is much thinner than the sclerotic and is very richly supplied with blood-vessels. Its inner surface is black because it is lined by a layer of cells full of granules of black pigment; a similar layer of cells loaded with granules of black pigment always covers the back of the iris. Just before the choroid becomes continuous with the iris it is thrown into a number of folds or plaits arranged in a radiating manner all round. These folds are called the **ciliary processes.** They, like the rest of the choroid, are covered by a layer of black pigment cells.

Situated at the back of the pupil, immediately behind the iris, is a transparent double convex body called the **crystalline**

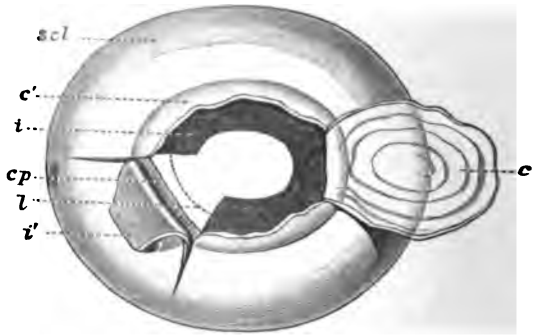


FIG. 96. — Dissection of bullock's eye.

scl, sclerotic; *c*, cornea turned aside; *c'*, edge of cornea left; *i*, iris; *i'*, part of iris turned aside to show ciliary processes, *cp*; *l*, dotted line to indicate edge of the lens.

lens. The crystalline lens is kept in place by a sheet of transparent tissue passing off from its edge, and attaching it all round to the choroid processes. This sheet, which forms a ring all round the lens, is called its **suspensory ligament.**

Lying on the choroid coat at the back of the eye is a third membrane. This is the important membrane of the eye, and is called the **retina.** The sclerotic and choroid coats are chiefly to protect the retina and to supply it with blood. The retina, which is loosely attached to the choroid, lines the hinder two-thirds of the eyeball and ends just behind the ciliary processes. The fibres of the optic nerve, entering the eyeball behind, pierce the sclerotic and choroid coats, and so pass into the retina in which they radiate out on all sides. Hence the retina may be considered as a thin cup-like expansion of the optic nerve. The large cavity between the crystalline lens in front and the retina behind is filled by a clear semi-fluid substance called the **vitreous humour**. The space between the cornea and the iris, called the anterior chamber of the eye, is in like manner full of fluid, which, in this case, is thin and watery, and called the **aqueous humour.**

Drive the sharp point of a fine pair of scissors through the cornea of the bullock's eye close to its edge and cut it away with a circular cut all round. A few drops of aqueous humour will run out. Notice that the cornea is a fairly thick but perfectly transparent membrane. It also appears now as a flat membrane, its bulging outwards in the eye being maintained by the aqueous humour. With the point of the scissors raise the pupil edge of the iris; notice that it is lying on the crystalline lens but not attached to it. Put the point of the scissors under the iris and make two radiating cuts outwards through the iris and its attachment to the coats of the eyeball. Turn the small piece of the iris which you have thus cut from the rest outwards and notice its attachment at the edge of the cornea, and under it the black ciliary processes projecting inwards. The ciliary processes are still attached to the lens by the suspensory ligament, so that you cannot turn the whole piece outwards without tearing something. Tear or cut a part of the suspensory ligament; by gentle squeezing the lens will then come away from the rest of the eyeball. It is a perfectly transparent body, convex both in front and behind, though more strongly so behind. Place it over printed paper and notice its magnifying power. The eye still contains

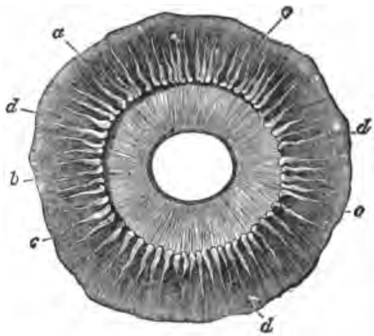


FIG. 97.—View of the iris and ciliary processes from behind.

a, circular fibres, and *b*, radiating fibres of the iris; *c*, ciliary processes lightly shaded on; *d*, choroid darkly shaded.

the vitreous humour, a clear colourless jelly-like material. Before disturbing the vitreous humour look through it on to the back of the eye; what you see is the greyish-yellow retina with a few of its larger blood-vessels. Turn out the vitreous humour and notice that the retina is a delicate membrane, very easily torn. When it is removed the choroid which is left behind appears darkly pigmented in some parts and iridescent (glistening with many colours) in others. This iridescence is peculiar to certain animals; it is present in the bullock's eye, but not in that of man. Lift up the choroid and notice that it is loosely attached to the tough outer coat, the sclerotic.

The Formation of Clear Images on the Retina.—The eye as the organ of sight has for its object the reception of light

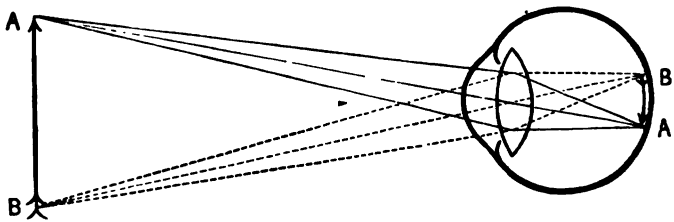


FIG. 98.—The formation of an image on the retina.

in such a way as to excite in the optic nerve impulses which, reaching the brain, produce the sensation of sight. The retina, a membrane of elaborate structure, contains the terminations of the optic nerve spread out in the form of a curved sheet. All other parts of the eye are either for the purpose of bringing the rays of light to the retina in such a way as to form on it clear images of the things we see or of protecting or nourishing the retina.

If a convex lens be fixed a few feet in front of a candle flame in an otherwise dark room, and a sheet of paper be held on the other side of the lens so as to form a screen, it will be found that at a certain distance of the paper from the lens a clear inverted image of the candle flame will be seen on the sheet of paper. The rays from the candle are then said to be brought to a focus on the screen. In the eye, images are formed in a similar way. The retina is the screen, and inverted images of external objects are formed on it by the crystalline lens, which, however, is helped by the curvature of the cornea; since the eyeball is filled with the aqueous and vitreous humour the convex surface of the cornea acts as a convex lens in the same way as a glass box with a convex front will act as a convex lens when filled with water. If, when a sharp image has been obtained in the simple experiment with the glass lens, the candle be moved nearer the lens, its image on the paper becomes indistinct, but a clear image is obtained by shifting the paper farther from the lens. On the other hand, if the candle be moved farther from the lens, the image becomes again indistinct, but may be made once more clear by moving the paper nearer the lens. If, however, the distance of the paper from the lens is kept the same after the candle has been shifted, a clear image of the candle can only be obtained by using a stronger lens in the first case and a weaker one in the second case. Thus we see that in order to bring the rays from a near object to a focus as soon as, that is, at the same place as, the rays from a distant object, a stronger lens, that is, a more sharply curved lens, must be used. The images formed on the screen are inverted images, and so are those on the retina; and such an inverted image may be seen on the retina of a bullock's eye by removing the hinder part of the sclerotic and choroid, and looking at the back of the retina when the eye is directed to a candle flame. Hence in a certain sense we may be said to see things upside down; but we see everything in this way, not some things only, and our sensations do not tell us that the images are inverted; we only learn this by examining other eyes. When the image of an object falls on the lower part of the retina, we do not know from the sensation that the lower part of the retina is being affected; we have a sensation of an object lying high up, so that we have to raise our hand if we try to touch it. Similarly a spot of light, rays from which affect the upper part of the retina, seems to us low down; one affecting the inner side, the nose side of the right eye, for instance, seems to be towards our right hand; one affecting the outer side, the cheek side of the same eye, seems to be on our left hand, and so on. We "refer," as it is said, every sensation started in the retina, to some or other part of the external world; we never think of the retina itself, and it is all the same to us whether all the images taken together on the retina be inverted or no.

Accommodation.—Put two needles upright into a board, one about 10 inches from the near end, and the other about 18 inches farther away. Close one eye, and with the other eye close to the end of the board, and almost in a line with the needles, look fixedly at the distant needle; it is seen clearly because when you look at it a clear image of it is formed on the retina; at the same time the near needle will be seen, but only indistinctly; it will appear not clear but blurred. Similarly, if the near needle is looked at fixedly, a clear image of it is formed on the retina, and at the same time a blurred and indistinct image of the distant needle. Certain changes can take place in the eye, so that it can be **accommodated** for the near needle or for the distant needle, but not for both at the same time. The objects we see may be at any distance from the eye, between a quite far distance, such as the horizon, and a short distance of about 10 inches, which is usually as near as things are held by most people. Throughout this wide range, and even up to 5 or 6 inches from the eye, we see things distinctly when we look at them, that is to say, clear images of objects are formed on the retina. Since no change in the distance of the screen, the retina, from the crystalline lens, can take place, this accommodation of the eye for objects at a varying distance can only be effected by changing the strength of the crystalline lens, that is, by changing its curvature, and it can be shown that this actually does take place. We might, it is true, gain the same result by changing the curvature of the cornea, but this does not take place. When the distant needle is looked at, in the experiment just mentioned, only a blurred image of the near needle is obtained, because the rays from the latter reach the retina before they are brought to a focus. This may be shown in the following way. With a needle prick two holes in a card about one-sixteenth of an inch apart, that is, closer together than the diameter of the pupil, so that you can look through both holes at once. Fix the card, with the holes horizontal, upright to the end of the board, 8 to 10 inches from the nearer needle. Hold the board to the window or facing a good light, close one eye, and with the other look through the holes at the needles. When the eye is fixed on one needle, one image of it is seen, and at the same time two images of the other. One image of the needle on which the eye is fixed is seen because the rays from it coming through the two holes are brought to the same focus on the retina; two

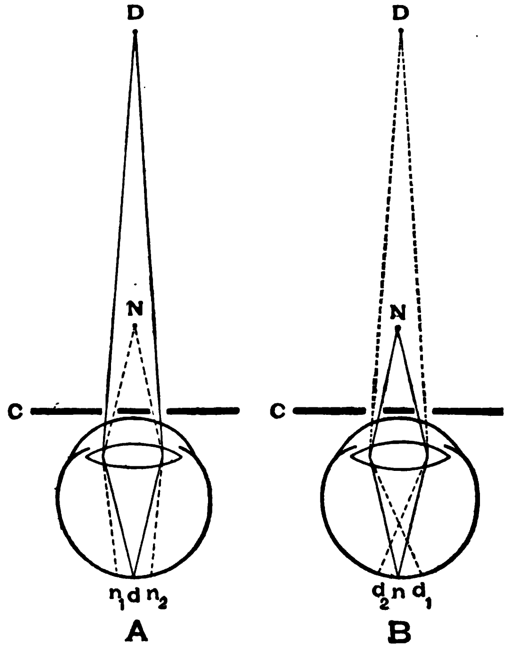


FIG. 99.—To illustrate accommodation.

images of the other needle are seen because the rays coming from it through the two holes are not brought to the same focus but strike the retina in different places. Fix the eye on the distant needle, and when you see the two images of the near needle, with another card close one hole; one of the two images of the near needle disappears; if the right-hand hole be closed, the left-hand image disappears; if the left-hand hole, the right-hand image (Fig. 99, A). Since an image seen on the left-hand side is one formed on the right-hand half of the retina, closing the right-hand hole has in this experiment cut off the image on the same side, the right-hand side, of the retina. This shows that the rays from the near needle coming through one hole have not crossed, or met, or been brought to a focus with those coming through the other hole before they struck the retina. That is, the crystalline lens, when accommodated for the distant needle, is not strong enough to bring the rays from the near needle to a focus on the retina. If, on the other hand, you fix the eye on the near needle, closing the right-hand hole will cut off the

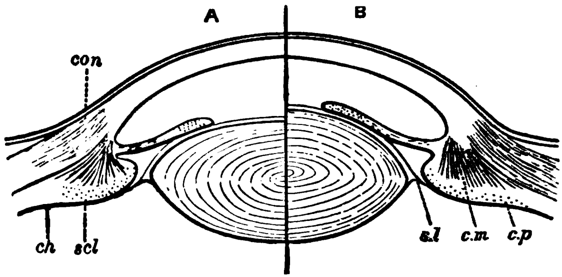


FIG. 100. — The changes in the lens in accommodation.

A, adjusted for distant; B, for near objects.
, cornea; *con*, conjunctiva; *scl*, sclerotic; *ch*, choroid; *c.p*, ciliary process; *c.m*, ciliary muscle; *s.l*, suspensory ligament.

right-hand image of the distant needle (Fig. 99, B). But the image seen on the right-hand is the one on the left-hand side of the retina, so that closing one hole in this case cuts off the image on the opposite side of the retina. This shows that the rays from the distant needle coming through the two holes have crossed each other, and were brought to a focus before they reached the retina. That is to say, the crystalline lens, when accommodated for the near needle, is too strong to bring the rays from the distant needle to a focus on the retina, but brings them to a focus too soon.

How does the lens change its curvature? The crystalline lens is elastic, that is, if its surface be made flatter by pressure, it recovers its original curvature and shape when the pressure is removed. We have seen that the lens is kept in its place by the suspensory ligament passing off from its edge to the ciliary processes all round it. The lens itself is enclosed by a transparent membrane, thicker in front than behind, called the capsule of the lens. It is to this capsule that the suspensory ligament is attached, but the suspensory ligament not only joins the capsule at the edge of the lens, but becomes directly continuous with the part of the capsule covering the front of the lens. This ligament is naturally tight, so that it is always more or less compressing the front of the lens, making this surface less convex than it would otherwise be. When we are looking at distant objects the pressure of the suspensory ligament is reducing the curvature of the front surface of the lens as much as possible, so as to make the lens weak. In this condition also is the lens when the eye is at rest, as during sleep. From the junction of the cornea and sclerotic there are fine unstriated muscle fibres passing downwards into the ciliary processes. These form a continuous ring of delicate muscle, called the **ciliary muscle**. When this muscle contracts, the ciliary processes with the loosely-attached choroid are drawn upwards towards the origin of the muscle from the junction of the firm and immovable sclerotic and cornea. As the ciliary processes are moved they carry with them the attachment of the suspensory ligament up nearer to the lens; thus the whole suspensory ligament is slackened. When we look at a near object this muscle contracts, and so slackens the suspensory ligament, and the lens, the pressure on its anterior surface being lessened, becomes by its own elasticity more convex.

Short Sight and Long Sight.— Ordinary persons cannot see things clearly when these are nearer than 5 or 6 inches to the eye, because the lens cannot be made convex enough to bring the rays to a focus. A short-sighted person sees things very well, and, in fact, best when they are as close as, or even much closer than this. But a short-sighted person cannot see things distinctly when they are some little distance off, because, however much his lens is flattened by the suspensory ligament, it brings the rays from a distant object to a focus in front of the retina. To correct this concave spectacles have to be used. The reason why the short-sighted eye brings the rays to a focus in front of the retina is usually not because the lens is naturally more convex, but because the retina is farther behind the lens than in the ordinary eye, the eye-ball being longer. On the other hand, in a long-sighted person the eyeball is shorter than usual and the retina lies too near the lens. He sees distant objects very well, but the rays from near objects are brought to a focus behind the retina, and so the image on the retina is indistinct. Convex spectacles have to be used. Old persons do not see clearly near objects for a different reason. In them the power of accommodation for near objects has more or less failed. Either the ciliary muscle does not contract so well, or the elasticity of the lens is impaired, so that when they look at near objects they cannot make the lens convex enough. Convex spectacles have to be used.

Action of the Iris.—If, when as clear an image as possible has been obtained in the simple experiment with the glass lens, a sheet of thick black paper with a hole in it be held immediately in front of the lens, a sharper, but less bright image will be obtained on the screen. The rays that pass through the outer part of a lens are brought to a focus a little in front of those that pass through the more central part, so that the image is not perfectly clear. By the use of the paper with the hole some of these outer rays are cut off. When the light is a long way from the lens, the hole in the paper will have to be a large one, in order to get the best image, as regards clearness and brightness taken together; or even letting the light come through the whole lens may give the best result. On the other hand, when the light is near the lens, a paper with a smaller hole will give the best result, because in this case more light is falling on the lens, and so more of the peripheral part can be cut off without making the image too dim. A photographer uses the "stops" he puts in front of the lens of his camera on the same principle, and he obtains inverted images on his sensitive plate in the same way as is done in this simple experiment. The iris in the eye acts in the same way. It cuts off the rays which would otherwise pass through the outer parts of the crystalline lens and be brought to a focus too soon.

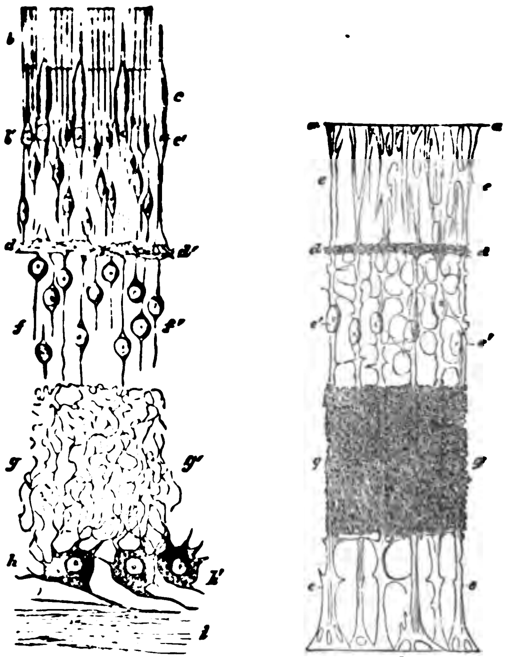
Shade the eye of a person with your hand and notice the size of the pupil, then let the light from a candle fall on the eye: you will notice the pupil quickly becomes smaller. Ask the person to look at some distant object, and notice the size of his pupil, then ask him to look at the point of a pencil put up about ten inches in front of him; as he does so you will notice his pupil becomes smaller. The pupil is larger when the light is dim, and also when we look at distant objects; it is smaller when the light is strong and when we look at near objects. How does the iris act so as to cover under some circumstances more, and under other circumstances less, of the crystalline lens?

The loose fibrous connective tissue of which the iris consists contains, in addition to pigment and other cells, unstriated muscle tissue. The muscular fibres are placed near the margin of the iris, around which they run in a circular manner. They form what is called a **sphincter muscle**. When this muscle contracts, the pupil becomes smaller, the iris covering more of the lens. When this muscle relaxes, the pupil becomes again larger. There is in addition at the back of the iris a thin layer of muscle fibres, or at least something like them, stretching outwards all round between the margin of the pupil and the outer edge of the iris. This layer can, by its contraction, draw back the iris, and so make the pupil larger. It is, however, chiefly the sphincter muscle which causes, by its contraction or its relaxation, the ordinary variations in the size of the pupil.

We have, so far, spoken of the mechanisms by which images of objects, whether near or far, or bright or dim, are formed on the retina; we must now turn to the retina itself, and see through what means the images on the retina excite the endings of the optic nerve, so that proper impulses are carried by it to the brain.

Structure of the Retina.—Just as there are in the organs of the sense of smell and of taste delicate, rod-shaped cells, or cells with delicate processes to receive the impressions and to transmit them to the sensory nerves concerned, so also in the retina the light excites rod-like processes of cells, and impressions pass from these to the optic nerves. These cells lie in the retina in a definite layer, called the layer of rods and cones.

The rod cells, which are the more numerous, and are closely packed together, consist of a rod-like process directed outwards towards the choroid, and of a tapering thread-like pro-



A B

FIG. 101.—Diagram of the nervous (A) and connective tissue elements (B) of the retina, supposed to be separated from one another.

A.—*b*, rods; *c*, cones; *b'* and *c'*, nuclei of the rods and cones; *d*, fine interwoven nervous filaments, from which fine filaments proceed, bearing the nuclei *f*, *f'*; from these filaments (*g*) proceed to the nerve cells *h*, *h'*; *i*, fibres of optic nerve, forming the innermost layer.

B.—*a*, external limiting membrane; *b*, internal limiting membrane; *e*, connective tissue fibres; *e'*, nuclei; *d* and *g*, fine granular layers.

cess, in which lies a nucleus, passing inwards towards the vitreous humour. The cones, which are interspersed among the rods, are sugar-loaf in shape, with a short, outer process, and with a narrow part, in which a nucleus lies, passing inwards. The inner processes of both the rods and cones break up into delicate fibrils, which meet the fibrils of other nucleated cells deeper in the retina, and these meet in their turn numerous fine nerve fibrils, springing from large nerve cells, in which the fibres of the optic nerve end. So that there is a connection, although not a simple one, between the fibres of the optic nerve and the rods and cones. These, the essential or nervous elements of the retina, are supported by a delicate connective tissue framework, and so the structure of the retina is made up.

The layer of rods and cones is at the outer surface of the retina, that is, the surface next to the choroid coat, while the layer of nerve fibres and of nerve cells is next to the vitreous humour; so that the light, since it comes through the vitreous humour, has to pass through the retina itself before it can excite the rods and cones; hence the whole retina is transparent. In the centre of the back of the eye is a small oval area, stained yellow and called the **yellow spot**. In the central part of this yellow spot all the parts of the retina except the layer of rods and cones are extremely thin, and here, unlike the rest of the retina, the cones are more numerous than the rods, indeed, at quite the centre are alone present, the rods being absent. Owing to this extreme thinness of the rest of the retina, light can here most easily pass to the cones. It is in the yellow spot that vision is most distinct; hence when we wish to see a thing distinctly we look straight at it, so that its image falls on the yellow spot. We see the other things around, but not so distinctly, since their images are falling on other parts of the retina.

Since the fibres of the optic nerve are on the inner side of the retina next to the vitreous humour, they must pierce not only the sclerotic and choroid coats, but the retina itself, before they spread out on its inner surface. There can, therefore, be no rods and cones at the spot where the optic nerve enters, which is not exactly at the centre of the back of the eye, but somewhat on the inner side of it nearer the nose. Light falling on this spot produces no effect. It is, therefore, called the **blind spot**. This is a proof that the sensation of light cannot arise without either rods or cones. The blindness of this spot can easily be shown by throwing an image on it. Hold the page you are reading about 12 inches away, or nearer if you are short-sighted, close the left eye and

look steadily with the right at the cross; the large dot will be seen as well. Now move the book slowly nearer, keeping the eye fixed on the cross; at a certain distance of the book the dot will disappear, but will reappear as the book is moved still closer. A, B, and C in Fig. 102 give the three positions. In all, the image of the cross falls on the yellow spot; the image of the dot falls in A between the yellow spot and the blind spot, in B on the blind spot itself, and in C on the other side of the blind spot near the nose.

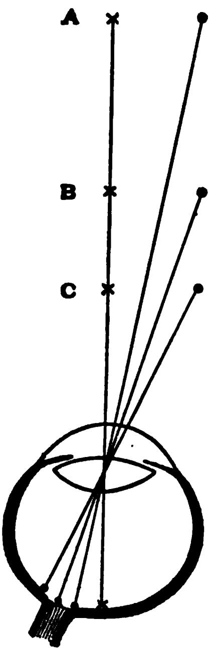


Fig. 102.

Visual Sensations. — The impression made by a flash of light on the retina lasts a certain time after the light is over. This is found to be about one-eighth of a second. So that if two flashes follow each other at a less interval of time than this their impressions catch each other up and produce one sensation only. This is why the spokes of a rotating wheel are not seen separately, and why a lighted stick twirled round gives the idea of a circle of fire.

The sensibility of the retina is easily tired. If a bright light is looked at for some time, and then the eye turned to a sheet of paper, a dark spot or dark image of the bright light is seen on the paper. This is because the light from that part of the paper is falling on a part of the retina which has been so fatigued that the rays fail to excite the sensation of light. Ordinary light, or white light as it is called, can be split up into a number of rays which, falling on the retina, produce the different sensations which we call colours. The retina may similarly be fatigued for one colour only, that is, for one portion only of white light. If, for instance, a bit of red paper lying on a sheet of white paper be looked at steadily for some time and then suddenly removed, a green patch will be seen where the red patch lay. This may be explained by supposing that the part of the retina on which the image of the red patch fell became tired to red rays, and after the red patch was removed, had no effect produced on it by the red rays which were present in the white light now coming from the same spot. It is as if the white light coming from the spot contained no red rays; but if you take the red rays out of white light, the result is green, or to put it in another way, red and green light mixed together make white light. Red and green are said to be complementary colours; when the eye is fatigued for one the other is seen. The same is true of yellow and blue.

To some persons the differences between some colours do not seem the same as they do to ordinary persons. They are **colour blind.** It is found, for instance, that rather more than one person in every hundred do not see red and green as distinct colours, and cannot tell the difference between red and green things except by their shade and brightness. This is a very important matter in the selection of engine-drivers and sailors. A few persons have been found to be totally colour blind, to whom everything appears of the same tint; but this is very rare.

The sensation of light may be excited in us by other means than the falling of light on the retina. Firm pressure on the eye causes a luminous image, and a blow on the eye, or a fall on the head, may cause flashes of light. These effects probably have their origin in the retina itself. It is worthy of notice that the sensations thus produced, though not caused by light, seem to us sensations of light; we "refer" them to sources of light in the world around us. This should be considered in connection with what was said a little while ago about the inverted image on the retina.

CHAPTER XX

THE EAR AND THE SENSE OF HEARING

JUST as in the sense of sight the waves of light produce their impression on the delicate processes of certain cells connected with the optic nerve, so in the sense of hearing the vibrations of sound act on the processes of certain cells connected with the auditory nerve. These cells are part of a delicate membrane of complicated structure lodged in spaces in the hard or petrous portion of the temporal bone. This part of the organ of hearing is called the **internal ear**. The sound waves are received by the **external ear**, that which we commonly call the "ear," and are conducted to the internal ear by the structures in the **middle ear**.

The External Ear. — The external ear consists of a plate of elastic cartilage of complicated shape, covered by connective tissue containing numerous blood-vessels, and then by the skin. Some small muscles are present passing to the ear from neighbouring parts. The external ear surrounds a more or less funnel-shaped opening, the beginning of a passage rather more than an inch long, the **external auditory canal**, which leads to the middle ear, from which it is shut off by a membraneous partition stretched across, called the **tympanic membrane**.

The Middle Ear. — The middle ear is a flattened drum-like cavity in the temporal bone, from the inner side of which a tube about 1½ inch long, called the **Eustachian tube**, leads to the upper part of the pharynx. The cavity, therefore, has access to the air in the pharynx; if the tympanic membrane did not exist there would be a passage from the opening of the ear through the middle ear into the pharynx. There are two other openings in the bony wall of the cavity of the middle ear, but both of these are closed by membranes; one is oval and called the **fenestra ovalis**, and the other is round and called the **fenestra rotunda**. They lead to the internal ear. Stretching across the cavity of the middle ear from the tympanic membrane to the fenestra ovalis is a chain formed by three very delicate bones. These are the **auditory ossicles**.

The first of these is somewhat hammer-shaped, and is called

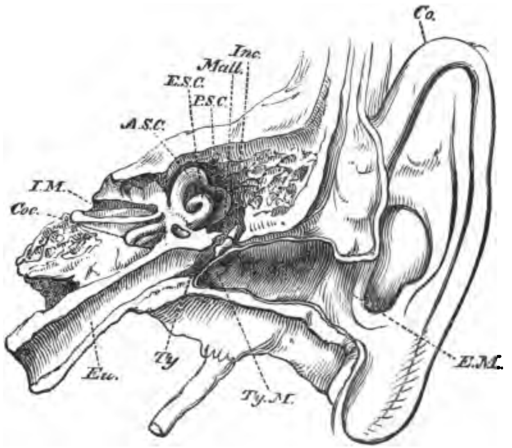


FIG. 103. — The parts of the ear.

Co, external ear; *E.M*, external auditory canal; *Ty.M*, tympanic membrane; *Inc. Mall*, incus malleus; *A.S.C*, *P.S.C*, *E.S.C*, the three semicircular canals; *Coc*, cochlea; *Eu*, Eustachian tube; *I.M*, canal through which the auditory nerve reaches the internal ear.

the **malleus**. The part like the handle of the hammer is attached vertically to the inner side of the tympanic membrane, and the rounded head of the hammer articulates with the second bone, the **incus** or anvil bone. The malleus has also a short, slender process attached by a ligament to the bony wall of the middle ear. The incus has a broad concave head, into which the head of the malleus fits, and two processes; the shorter process is attached to the wall of the middle ear by a ligament, while the longer process articulates with the third bone, the **stapes** or stirrup bone. The stapes, which is exactly like a stirrup, lies nearly horizontally; the top of the arch of the stirrup is attached to the incus, and the foot-plate of the stirrup fits into the fenestra ovalis, and is attached to the membrane covering it. Two small muscles pass from the wall of the cavity to the ossicles: one is attached to the handle of

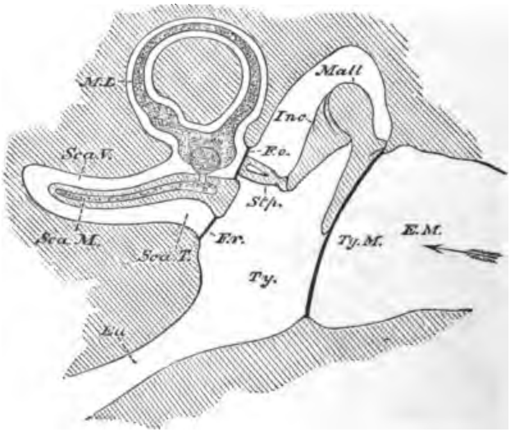


FIG. 104.— Diagram of the auditory ossicles and the parts of the internal ear.

E.M, external auditory canal; *Ty.M*, tympanic membrane; *Ty*, middle ear cavity; *Mall*, malleus; *Inc*, incus; *Stp*, stapes; *F.o*, fenestra ovalis; *F.r*, fenestra rotunda; *Eu*, Eustachian tube; *M.L*, membraneous labyrinth, one semicircular canal represented; *Sca.M*, canal of the cochlea; *Sca.V*, the part of the cavity of the cochlea above the canal of the cochlea; *Sca.T*, the part below.

the malleus, and its action tightens the tympanic membrane; the other is attached to the arch of the stapes, and its action tightens the membrane closing the fenestra ovalis.

The Internal Ear. — The essential part of the organ of hearing — that in which the auditory nerve ends — consists of a membrane in the form of a closed bag, consisting of different parts, each of a peculiar and complicated form. The membraneous bag, with its different parts, lies in a cavity of similar peculiar shape situated in the petrous part of the temporal bone. This cavity is a completely closed one, the two openings from it through the bone into the middle ear being closed, as already mentioned, by membrane. Surrounding the membraneous bag and its various parts, and separating it from the bony walls of the cavity, is a lymph-like fluid, the **perilymph.** At certain parts, namely, where fibres of the auditory nerve pass from canals in the bone to it, the membraneous bag is firmly attached to the bony walls; otherwise the bag is free, or only loosely attached by bands of connective tissue.

The central part of the membraneous bag is an oval sac,

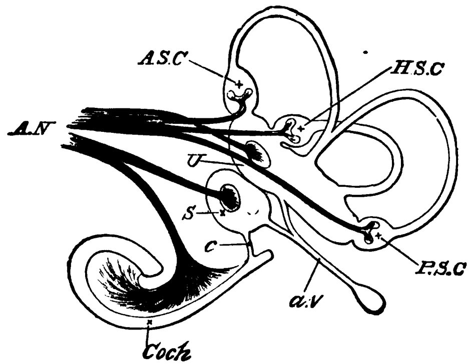


FIG. 105. — Diagram to show how the auditory nerve is distributed to the membraneous labyrinth and cochlea.

A.N, auditory nerve; *U*, utricle; *S*, saccule; *A.S.C*, *H.S.C*, *P.S.C*, the dilated end of the three semicircular canals; *Coch*, cochlea; *c*, canal joining it to the saccule; *a.v*, the communicating tube between the utricle and saccule.

called the **utricle.** From this spring three hoop-like canals, called the **semicircular canals,** which lie in corresponding canals in the bone. In a man standing upright, one of these lies horizontally and the other two lie vertically, but at right angles to one another. Near the utricle, and in roundabout communication with it, is another small sac, called the **saccule.** The two sacs together form the **vestibule,** and this, with the semicircular canals, is spoken of as the **membraneous**

labyrinth, the bony cavity in which they lie being the osseous labyrinth. The membraneous labyrinth contains a fluid called the **endolymph**.

One end of each semicircular canal is enlarged to a small bulb, and is here closely fixed to the bone; for it is at this spot that fibres of the auditory nerve pass to the membrane, and end in it in a small patch. Other branches of the auditory nerve end in similar patches in the membrane of the utricle and in that of the saccule. The membrane

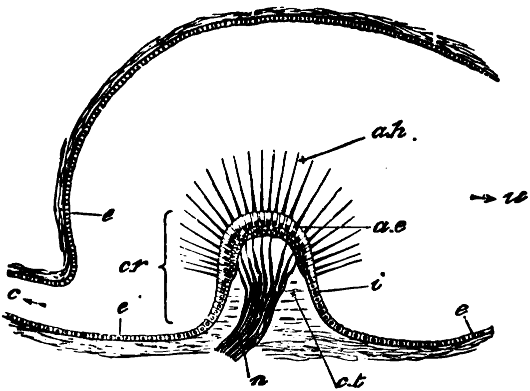


FIG. 106. — Section lengthwise through the dilated end of a semicircular canal.

c, part leading to the canal; *u*, part leading to the utricle; *e*, ordinary epithelium lining the greater part of the canal; *c.r*, crest or patch of auditory epithelium, *a.e*; *i*, intermediate epithelium; *a.h*, auditory hairs; *c.t*, connective tissue; *n*, fibres of auditory nerve.

itself consists of fibrous connective tissue lined internally by an epithelium consisting of a layer of cubical cells. At the patches where the auditory nerve ends the membrane is much thicker, and the epithelium is specially modified for the reception of sound vibrations. This part is known as the **auditory epithelium**.

The auditory epithelium consists of several layers of cells. All these cells are very delicate, and while some are cylindrical in form, others are spindle-shaped. From the surface of the epithelium stiff hair-like processes connected with the cells project into the endolymph. The fibres of the auditory nerve end by breaking up into a network of fine fibrils lying among and in close contact with the cells.

The Cochlea. — Somewhat as the utricle gives off the semicircular canals, so the saccule gives off a canal containing also endolymph, called the canal of the cochlea. This canal does not, however, return to the saccule as a semicircular canal returns to the utricle, but has a blind end. It is, moreover, coiled in the form of a spiral of two and a half turns, forming a small cone called the cochlea. It lies in a spiral canal in the bone, but is not merely loosely attached here and there to the wall of the cavity as are the semicircular canals, but closely fixed all the way along to the outer wall of the spiral cavity, and also to a ledge of bone projecting inwards from the inner wall or wall next the axis of the spiral. By these attachments of the canal of the cochlea the cavity in the bone is divided into two parts, one above and one below the canal of the cochlea, which only communicate with one another at the end of the cavity, that is, at the top of the spiral after the canal of the cochlea has ended. Both parts of the cavity contain perilymph. If the part of the cavity which lies above the canal of the cochlea is traced down the spiral it is found to be continuous with the cavity in which the saccule, utricle, and semicircular canals lie, and so leads to the fenestra ovalis. The cavity below the canal of the cochlea leads to the fenestra rotunda, where it is separated by membrane from the cavity of the middle ear. We thus see how the fenestra rotunda and the fenestra ovalis lie in the wall of one and the same cavity, although this cavity is of a very complicated shape, and the passage from one fenestra to the other is a very roundabout one.

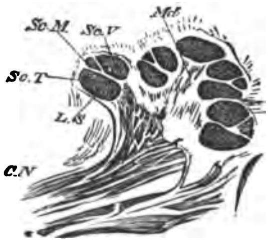


FIG. 107. — A section through the axis of the cochlea.

Md, the bony axis; *Sc.M*, canal of cochlea; *Sc.V*, the part of the bony cavity above the canal of the cochlea *Sc.T*, the part below; *L.S*, the spiral ledge projecting from the axis; *C.N*, branch of auditory nerve.

The canal of the cochlea is not round but triangular in section, and one side, namely, that forming as it were the base of the triangle carries the auditory epithelium, and is known as the **basilar membrane**. This auditory epithelium

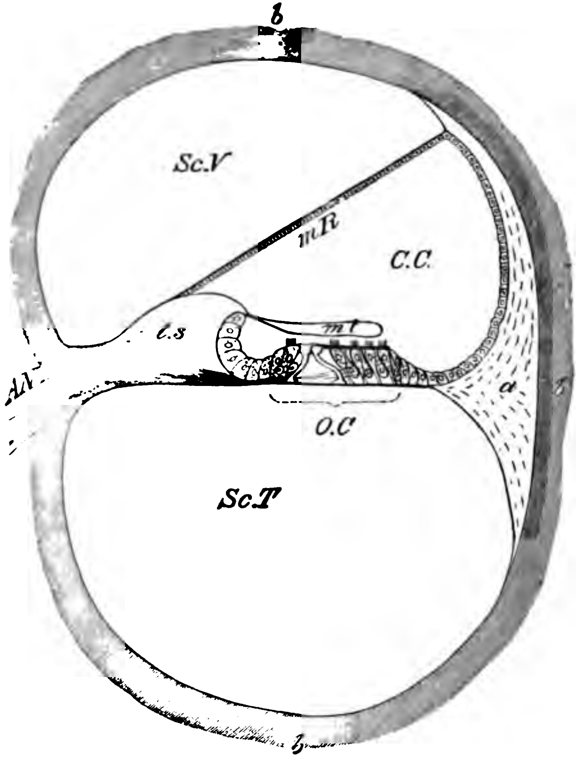


FIG. 108. — Diagram of a section of a coil of the cochlea.

C.C, canal of the cochlea; *mR*, its upper wall; *Sc.V*, the part of the bony cavity above the canal of the cochlea; *Sc.T*, the part below it; *O.C*, the organ of Corti on the basilar membrane; *A.N*, branch of auditory nerve in the central column of the spiral; *a*, connective tissue cushion to which the basilar membrane is attached; *b*, the bony walls; *m.t*, a membrane lying over the organ of Corti; *l.s*, the spiral ledge projecting from the axis.

is not confined to mere patches, but is continued along the whole length of the spiral. A branch of the auditory nerve running up the axis of the spiral sends off, all the way up, fibres, which, running in the basilar membrane, become connected with the auditory epithelium along its whole length. The auditory epithelial cells are arranged on the basilar membrane all the way from the bottom to the top of the spiral in a remarkable manner, and the structure so formed is spoken of as the **organ of Corti.** In a section across a coil of the cochlea, at about the middle of the basilar membrane, may be seen a pair of rod-like cells called the rods of Corti, propped up one against the other, so as to form an arch. These pairs of rods occur one after the other all along the tube of the cochlea, there being about 5000 pairs altogether. On the outer side of the rods of Corti are several rows of epithelial cells bearing short hair-like processes, and there is one row of similar cells on the inner side of the rods. They are called the outer and inner **hair cells.** The fibres of the auditory nerves can be traced up to and are in connection with these hair cells.

Sound

Anything causing a sound either vibrates bodily itself or some of its particles vibrate, and as a consequence the air around it is thrown into waves; these waves, if of sufficient intensity and frequency, produce, on reaching the ear, the sensation which we call sound.

Sound travels through the air at the rate of 1100 feet a second. It is also transmitted through liquids and solids. A musical sound or note is produced when the vibrations follow each other regularly, that is, when similar vibrations are repeated so many times a second; when the vibrations are irregular the sound is called a "noise." A musical sound or a noise may be loud or feeble; this depends on the strength with which the vibrations affect the ear. A musical sound has what is called a "pitch," low or high; this depends on the rapidity with which the vibrations are repeated; when they are repeated slowly the pitch is low, when rapidly high. Besides pitch and loudness a musical sound has what is called "quality," the same note struck on a piano and on a violin seems to us in some way different. This difference is due to the fact that very many musical sounds consist not of one set of vibrations only, but of several, of a main set of vibrations called the fundamental tone, and of others, and these vary, called partial tones or overtones.

The Transmission of Vibrations in the Ear.—Sound waves are collected by the external ear, pass along the external auditory canal, and striking on to the tympanic membrane, set this vibrating at a corresponding rate and intensity. The membrane in its vibration carries with it the handle of the malleus, and this leads to a similar movement of the long process of the incus, and so of the stapes, which this carries. The movement of the stapes sets vibrating the membrane which, with the foot-plate of the stapes, closes the fenestra ovalis. The to and fro movement of this membrane sets up vibrations, which travel through the perilymph, surrounding the vestibule, semicircular canals, and canal of the cochlea, till they strike finally the membrane covering the fenestra rotunda. The vibrations in the perilymph are transmitted through the thin walls of the vestibule, semicircular canals, and canal of the cochlea, and lead to vibrations of the endolymph. These affect the cells of the auditory epithelium in such a way as to give rise to nervous impulses in the fibres of the auditory nerve, and these impulses, on reaching the brain, excite in us the sensation of sound. It is undoubtedly the hair cells of the organ of Corti in the cochlea which are affected when we hear; whether we also hear by means of the auditory epithelium of the patches on the semicircular canals and vestibule is not so clear.

The lowest note that most persons can hear is one of thirty vibrations a second. The highest note varies very much. Some persons can hear a note of 30,000 vibrations a second, while others cannot hear the squeak of a bat or mouse or the chirp of a sparrow, which are much lower notes. Very likely many insects make sounds which are not heard by us.

CHAPTER XXI

THE LARYNX—VOICE AND SPEECH

THE voice is produced in the larynx by the vibrations of the edge of two folds of the mucous membrane lining it. These folds are called **vocal cords.** Their vibration is caused by a blast of air driven out between them.

Obtain the larynx of a sheep from a butcher. You will notice at once the large open tube, the trachea, passing out from it below, covered at the sides and in front by muscles and fat. Above the trachea and to the front is the prominent angle of the largest cartilage of the larynx. It is this that forms the projection, popularly known as Adam's apple, which is very marked in the neck of some persons. This will be covered with muscles passing downwards by the side of the trachea and upwards to an arch of bone, the **hyoid bone,** which you can feel in the mass of tissue above. The hyoid bone forms an arch of bone in front but is incomplete behind. Muscles pass from it above into the tongue.

The larynx is somewhat flat behind, and closely adhering to it is the œsophagus, a collapsed muscular tube. Find the lower cut end of this, and then with scissors cut it open to the top. The cavity you have then laid open is wider above than below; this upper part is the pharynx. Notice the smooth whitish mucous membrane lining the pharynx and œsophagus. Projecting backwards into the pharynx from its front wall is the prominent, almost erect cartilage, the epiglottis. Immediately below this is the opening into the larynx, the glottis, which is guarded also by two cushions of cartilage, covered of course by the lining mucous membrane. Press down the tip of the epiglottis and notice that it completely closes the opening into the larynx, and leaves a straight smooth passage from the pharynx on into the œsophagus.

Remove the loose muscles and fat from the trachea and from one side of the larnyx. Tear away the œsophagus, beginning from the lower end, and proceed upwards as far as the glottis, cutting as you go the connective tissue attaching the œsophagus to the trachea and larynx. Stretch the trachea and examine its rings of cartilage more closely. Notice that the top one is broader than the others, but like them is also incomplete behind. Just above this is the **cricoid cartilage** of the larynx, a complete ring, shaped like a signet ring, narrow in front, but very broad behind, forming in fact a cartilaginous wall for the greater part of the back of the larynx. Above this is a broad V-shaped cartilage, the **thyroid cartilage**, forming a prominent ridge in front and flat sheets at the sides. Notice that the thyroid does not extend quite to the back, but ends at the sides, its edge being produced above and below into horn-like processes. The thyroid cartilage is attached to the cricoid cartilage below, by membrane and muscles only, except where the tip of the lower horn on each side forms a joint with the cricoid. The thyroid cartilage can be tilted up and down, these joints acting as hinges. At the back of the larynx, seated on the top of the broad part of the cricoid are two small cartilages called the **arytenoid cartilages**. These, with the mucous membrane on them, form the two cushions mentioned above, which help to guard the glottis.

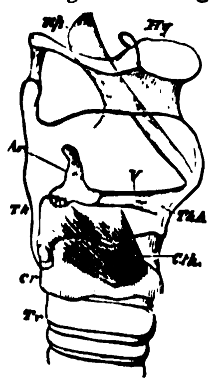


FIG. 109. — Diagram to show the structere of the larynx.

The thyroid cartilage (*Th*) is supposed to be transparent so that the right arytenoid cartilage (*Ar*), thyro-arytenoid muscle (*ThA*), vocal cord (*V*), and the upper part of the cricoid cartilage are represented. *C.th*, the crico-thyroid muscle; *Tr*, trachea; *Hy*, hyoid bone; *Ep*, epiglottis.

There is a muscle arising from each side of the cricoid cartilage which, passing upwards and backward, is inserted into the thyroid cartilage; this is called the **crico-thyroid muscle**. When this muscle contracts the front of the thyroid cartilage is drawn down, or when the thyroid is fixed, as it may be by the action of other muscles attached to it, the front of the cricoid cartilage is drawn up while its back goes down, in a see-saw manner. Either of these actions increases the distance of the top of the back of the cricoid and of the arytenoid cartilages on it from the front of the thyroid. Small muscles pass from the back of the cricoid to the arytenoid cartilages; these in contracting draw the arytenoid cartilages apart from each other and so widen the glottis. Another muscle passes from one arytenoid cartilage to the other, and by its action draws them together and so narrows the glottis.

Cut the thyroid cartilage upwards on one side in two places, one near the front angle and the other near the hinder edge, so as to remove the greater part of it on one side. Immediately under it, and only slightly adherent to it, is a broad band of muscle passing from the front angle of the thyroid cartilage backwards to the arytenoid cartilage of the same side; this is called the **thyro-arytenoid** muscle. When this muscle is cut through there is still the mucous membrane lining the cavity of the larynx. Cut this membrane through and remove one side of the cricoid cartilage and slit open the side of the trachea, so as to well expose the interior of the larynx to view. Notice that the smooth mucous membrane is everywhere even, except in one place on each side where it is thrown into a thick rounded fold running from the front of the thyroid cartilage backwards to the arytenoid cartilage. These two folds, one on each side, are the **vocal cords**.

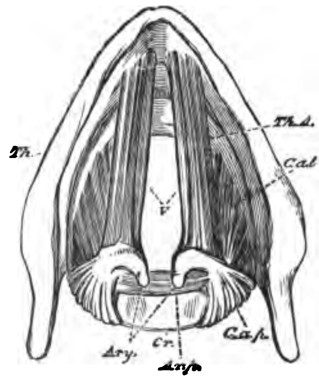


FIG. 110.—The glottis viewed from above. *Th*, thyroid cartilage; *Cr*, cricoid cartilage; *Ary*, arytenoid cartilages; *Arp*, the muscle between them; *C.a.l*, and *C.a.p*, muscles passing from the cricoid to the arytenoid cartilages; *Th.A*, thyro-arytenoid muscle; *V*, vocal cords.

When the arytenoid cartilages are wide apart the aperture between the vocal cords, the glottis, has the form of a V with the broad part behind. The vocal cords are in this position when they are at rest, that is, when ordinary respiration is going on, but no voice is being produced. When voice is being produced the arytenoids are drawn together, and so the vocal cords become parallel, and the aperture between them becomes merely a narrow slit. At the same time the vocal cords are tightened by the crico-thyroid muscle increasing the distance of the front of the thyroid from the arytenoids

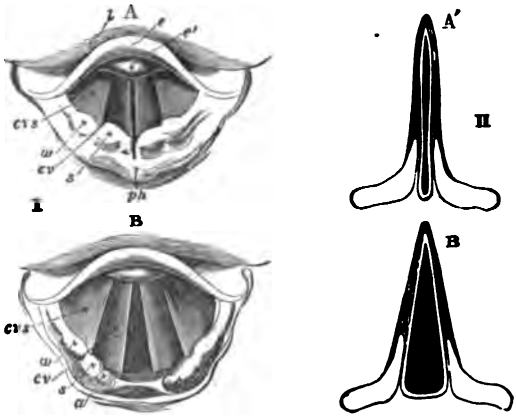


FIG. 111.

I. View of the human larynx from above as seen by a small mirror held at the back of the mouth when light is reflected down the throat. *A*, condition when voice is being produced, *B*, when no voice is being produced. *e*, epiglottis, *cv*, vocal cords; *cvs*, so-called false vocal cords, folds of mucous membrane lying above the real vocal cords; *a*, elevation caused by arytenoid cartilages; *s*, *w*, elevations caused by small cartilages connected with the arytenoids; *l*, root of tongue.

II. Diagrams of the glottis in the two conditions.

in the manner already explained. By the stronger or weaker action of these muscles, with the opposite effect produced by the muscles which slacken the vocal cords (such as the thyro-arytenoid muscles running parallel with them), the tension of the vocal cords can be varied within wide limits. On this depends the pitch of the note produced, when the cords are set in vibration by a blast of expired air. A good singer can accurately adjust the different muscles so as to produce the proper tension of the cords, so that their vibration will give the note he wishes. In women and in boys the vocal cords are shorter and the whole larynx smaller than in men, and so higher notes are produced. Similarly tenor and bass voices, or alto and soprano voices depend on small differences in the construction of the larynx.

Speech. — Speech is produced by modifying the voice arising in the larynx, by changing the form of the cavity of the pharynx and mouth, by means of the tongue and lips.

Pronounce the pure vowel sounds

E (as in he)	A (as in hay)	A (as in ah)
O (as in or)	O (as in oh)	OO (as in cool)

and notice that they are produced by varying the form of the cavity of the mouth, and the shape of the opening of the mouth by drawing in or thrusting out the lips. The consonants F, G, J, L, R, S, V, Z, are similarly produced by varying the form of the cavity of the mouth by means of the lips and tongue. The consonants M and N, are produced by stopping the current of air through the mouth, for M by closure of the lips, and for N by pressing the tongue against the palate. Other consonants are called "explosive," because they are produced by blocking the outgoing air both through the nose and mouth, and then suddenly bursting open the latter. Such are B, P, T, D, and K, and G (hard as in go).

Whispering is due to a faint noise produced by the friction of the air as it passes through the glottis, the sound being modified to a feeble speech by movements of the tongue and lips; there is no vibration of the vocal cords.

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THE END